

## ACTIVE AGENT DELIVERY SYSTEMS AND METHODS FOR PROTECTING AND ADMINISTERING ACTIVE AGENTS

### Field of the Invention

5           The present invention relates to active agent delivery systems and, more specifically, to compositions that comprise polypeptides covalently attached to active agents and methods for protecting and administering active agents.

### Background of the Invention

10           Active agent delivery systems are often critical for the effective delivery of a biologically active agent (active agent) to the appropriate target. The importance of these systems becomes magnified when patient compliance and active agent stability are taken under consideration. For instance, one would expect patient compliance to increase markedly if an active agent is administered orally in lieu of an injection or another invasive technique. Increasing the stability of the active agent, such as  
15           prolonging shelf life or survival in the stomach, will assure dosage reproducibility and perhaps even reduce the number of dosages required which could improve patient compliance.

20           Absorption of an orally administered active agent is often blocked by the harshly acidic stomach milieu, powerful digestive enzymes in the GI tract, permeability of cellular membranes and transport across lipid bilayers. Incorporating adjuvants such as resorcinol, surfactants, polyethylene glycol (PEG) or bile acids enhance permeability of cellular membranes. Microencapsulating active agents using protenoid microspheres, liposomes or polysaccharides have been effective in abating enzyme degradation of the active agent. Enzyme inhibiting adjuvants have also been

used to prevent enzyme degradation. Enteric coatings have been used as a protector of pharmaceuticals in the stomach.

Active agent delivery systems also provide the ability to control the release of the active agent. For example, formulating diazepam with a copolymer of glutamic acid and aspartic acid enables a sustained release of the active agent. As another example, copolymers of lactic acid and glutaric acid are used to provide timed release of human growth hormone. A wide range of pharmaceuticals purportedly provide sustained release through microencapsulation of the active agent in amides of dicarboxylic acids, modified amino acids or thermally condensed amino acids. Slow release rendering additives can also be intermixed with a large array of active agents in tablet formulations.

Each of these technologies imparts enhanced stability and time-release properties to active agent substances. Unfortunately, these technologies suffer from several shortcomings. Incorporation of the active agent is often dependent on diffusion into the microencapsulating matrix, which may not be quantitative and may complicate dosage reproducibility. In addition, encapsulated drugs rely on diffusion out of the matrix, which is highly dependant on the water solubility of the active agent. Conversely, water-soluble microspheres swell by an infinite degree and, unfortunately, may release the active agent in bursts with little active agent available for sustained release. Furthermore, in some technologies, control of the degradation process required for active agent release is unreliable. For example, an enterically coated active agent depends on pH to release the active agent and, as such, is difficult to control the rate of release.

In the past, use has been made of amino acid side chains of polypeptides as pendant groups to which active agents can be attached. These technologies typically require the use of spacer groups between the amino acid pendant group and the active agent. The peptide-drug conjugates of this class of drug delivery system rely on enzymes in the bloodstream for the release of the drug and, as such, are not used for oral administration. Examples of timed and targeted release of injectable or subcutaneous pharmaceuticals include: linking of norethindrone, via a hydroxypropyl spacer, to the gamma carboxylate of polyglutamic acid; and linking of nitrogen mustard, via a peptide spacer, to the gamma carbamide of polyglutamine. Dexamethasone has been covalently attached directly to the beta carboxylate of polyaspartic acid without a spacer group. This prodrug formulation was designed as a colon-specific drug delivery system where the drug is released by bacterial hydrolytic enzymes residing in the large intestines. The released dexamethasone active agent, in turn, was targeted to treat large bowel disorders and was not intended to be absorbed into the bloodstream. Yet another technology combines the advantages of covalent drug attachment with liposome formation where the active ingredient is attached to highly ordered lipid films (known as HARs) via a peptide linker. Thus, there has been no drug delivery system, heretofore reported, that incorporates the concept of attaching an active ingredient to a polypeptide pendant group with its targeted delivery into the bloodstream via oral administration.

It is also important to control the molecular weight, molecular size and particle size of the active agent delivery system. Variable molecular weights have unpredictable diffusion rates and pharmacokinetics. High molecular weight carriers are digested slowly or late, as in the case of naproxen-linked dextran, which is digested almost exclusively in the colon by bacterial enzymes. High molecular

weight microspheres usually have high moisture content which may present a problem with water labile active ingredients. Particle size not only becomes a problem with injectable drugs, as in the HAR application, but absorption through the brush-border membrane of the intestines is limited to less than 5 microns.

## 5 Summary of the Invention

The present invention provides covalent attachment of active agents to a polymer of peptides or amino acids. The invention is distinguished from the above mentioned technologies by virtue of covalently attaching the active agent, which includes, for example, pharmaceutical drugs and nutrients, to the N-terminus, the C-terminus or directly to the amino acid side chain of an oligopeptide or polypeptide, also referred to herein as a carrier peptide. In certain applications, the polypeptide will stabilize the active agent, primarily in the stomach, through conformational protection. In these applications, delivery of the active agent is controlled, in part, by the kinetics of unfolding of the carrier peptide. Upon entry into the upper intestinal tract, indigenous enzymes release the active ingredient for absorption by the body by selectively hydrolyzing the peptide bonds of the carrier peptide. This enzymatic action introduces a second order sustained release mechanism.

The invention provides a composition comprising a polypeptide and an active agent covalently attached to the polypeptide. Preferably, the polypeptide is (i) an oligopeptide, (ii) a homopolymer of one of the twenty naturally occurring amino acids (L or D isomers), or an isomer, analogue, or derivative thereof, (iii) a heteropolymer of two or more naturally occurring amino acids (L or D isomers), or an isomer, analogue, or derivative thereof, (iv) a homopolymer of a synthetic amino acid, (v) a

heteropolymer of two or more synthetic amino acids or (vi) a heteropolymer of one or more naturally occurring amino acids and one or more synthetic amino acids.

The active agent preferably is covalently attached to a side chain, the N-terminus or the C-terminus of the polypeptide. In a preferred embodiment, the active agent is a carboxylic acid and is covalently attached to the N-terminus of the polypeptide. In another preferred embodiment, the active agent is an amine and is covalently attached to the C-terminus of the polypeptide. In another preferred embodiment, the active agent is an alcohol and is covalently attached to the C-terminus of the polypeptide. In yet another preferred embodiment, the active agent is an alcohol and is covalently attached to the N-terminus of the polypeptide.

The composition of the invention can also include one or more of a microencapsulating agent, an adjuvant and a pharmaceutically acceptable excipient. The microencapsulating agent can be selected from polyethylene glycol (PEG), an amino acid, a sugar and a salt. When an adjuvant is included in the composition, the adjuvant preferably activates an intestinal transporter.

Preferably, the composition of the invention is in the form of an ingestible tablet, an intravenous preparation or an oral suspension. The active agent can be conformationally protected by folding of the polypeptide about the active agent. In another embodiment, the polypeptide is capable of releasing the active agent from the composition in a pH-dependent manner.

The invention also provides a method for protecting an active agent from degradation comprising covalently attaching the active agent to a polypeptide.

The invention also provides a method for controlling release of an active agent from a composition wherein the composition comprises a polypeptide, the method comprising covalently attaching the active agent to the polypeptide.

The invention also provides a method for delivering an active agent to a patient, the patient being a human or a non-human animal, comprising administering to the patient a composition comprising a polypeptide and an active agent covalently attached to the polypeptide. In a preferred embodiment, the active agent is released from the composition by an enzyme-catalyzed release. In another preferred embodiment, the active agent is released in a time-dependent manner based on the pharmacokinetics of the enzyme-catalyzed release. In another preferred embodiment, the composition further comprises a microencapsulating agent and the active agent is released from the composition by dissolution of the microencapsulating agent. In another preferred embodiment, the active agent is released from the composition by a pH-dependent unfolding of the polypeptide. In another preferred embodiment, the active agent is released from the composition in a sustained release. In yet another preferred embodiment, the composition further comprises an adjuvant covalently attached to the polypeptide and release of the adjuvant from the composition is controlled by the polypeptide. The adjuvant can be microencapsulated into a carrier peptide-drug conjugate for biphasic release of active ingredients.

The invention also provides a method for preparing a composition comprising a polypeptide and an active agent covalently attached to the polypeptide. The method comprises the steps of:

(a) attaching the active agent to a side chain of an amino acid to form an active agent/amino acid complex;

(b) forming an active agent/amino acid complex N-carboxyanhydride (NCA) from the active agent/amino acid complex; and

(c) polymerizing the active agent/amino acid complex N-carboxyanhydride (NCA).

5 In a preferred embodiment, the active agent is a pharmaceutical agent or an adjuvant. In another preferred embodiment, steps (a) and (b) are repeated prior to step (c) with a second active agent. When steps (a) and (b) are repeated prior to step (c) with a second agent, the active agent and second active agent can be copolymerized in  
10 step (c). In another preferred embodiment, the amino acid is glutamic acid and the active agent is released from the glutamic acid as a dimer upon a hydrolysis of the polypeptide and wherein the active agent is released from the glutamic acid by coincident intramolecular transamination. In another preferred embodiment, the glutamic acid is replaced by an amino acid selected from the group consisting of aspartic acid, arginine, asparagine, cysteine, lysine, threonine, and serine, and wherein  
15 the active agent is attached to the side chain of the amino acid to form an amide, a thioester, an ester, an ether, a urethane, a carbonate, an anhydride or a carbamate. In yet another preferred embodiment, the glutamic acid is replaced by a synthetic amino acid with a pendant group comprising an amine, an alcohol, a sulfhydryl, an amide, a urea, or an acid functionality.

20 It is to be understood that both the foregoing general description and the following detailed description are exemplary, but are not restrictive, of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in connection with the accompanying drawing. Included in the drawing are the following figures.

Fig. 1 illustrates an acid active agent/N-terminus scheme of the invention.

5 Fig. 2 illustrates an amine active agent/C-terminus scheme of the invention.

Fig. 3 illustrates an alcohol active agent/N-terminus scheme of the invention.

Fig. 4 illustrates an alcohol active agent/glutamic acid dimer preparation and conjugation scheme of the invention.

10 Fig. 5 illustrates a mechanism of alcohol active agent from glutamic acid dimer scheme.

Fig. 6 illustrates the in situ digestion of polythroid in intestinal epithelial cell cultures.

Fig. 7 illustrates basolateral T4 concentrations.

Fig. 8 illustrates the polythroid concentration of basal versus basolateral.

15 Fig. 9 illustrates T4 analysis in gastric simulator versus intestinal simulator.

Fig. 10 illustrates T3 analysis in gastric simulator versus intestinal simulator.



## DETAILED DESCRIPTION OF THE INVENTION

The present invention provides several benefits for active agent delivery. First, the invention can stabilize the active agent and prevent digestion in the stomach. In addition, the pharmacologic effect can be prolonged by delayed release of the active agent. Furthermore, active agents can be combined to produce synergistic effects. Also, absorption of the active agent in the intestinal tract can be enhanced. The invention also allows targeted delivery of active agents to specific sites of action.

The composition of the invention comprises a polypeptide and an active agent covalently attached to the polypeptide. Active agents may be selected from the list in TABLE 1, either alone or in combination with other agents on the list.

**TABLE 1**

abacavir sulfate	
abarelix	
acarbose	
Acetaminophen	
Acetaminophen;	Codeine
phosphate	
Acetaminophen;	Propoxyphene
napsylate	
Acetylsalicylic acid	
Acitretin	
activated protein C	
Acyclovir	
adefovir dipivoxil	
adenosine	
Adrenocorticotrophic hormone	
Albuterol	
alendronate sodium	
Allopurinol	
alpha 1 proteinase inhibitor	
Alprazolam	

Carisoprodol



clorpheniramine tannate

Clozapine

Colestipol HCL

conivaptan

Cyclobenzaprine HCL

Cyclophosphamide

Cyclosporine

dalteparin sodium

dapitant

desmopressin acetate

Desogestrel; ethinyl estradiol

Dextroamphetamine sulfate

dextromethorphan

Diazepam

ABT 594

Diclofenac sodium

diclofenac sodium, misoprostol

Dicyclomine HCL

didanosine

Digoxin

diltiazem hydrochloride

Dipyridamole

divalproex sodium

d-methylphenidate

dolasetron mesylate monohydrate

donepezil hydrochloride

Dopamine/D5W

Doxazosin

doxorubicin hydrochloride

duloxetine

dutasteride

ecadotril

ecopipam

edodekin alfa (Interleukin-12)

efavirenz

ABT 773

emivirine

Enalapril

enapril

maleate,

hydrochlorothiazide

eniluracil  
enoxaparin sodium

epoetin alfa recombinant

eptifibatide  
Ergotamine Tartrate  
Erythromycin  
ALT 711

esatenolol  
Esterified                      estrogens;  
,Methyltestosterone  
Estrogens, conjugated  
Estrogens,                      conjugated;  
medroxyprogesterone acetate  
Estropipate  
etanercept  
ethinyl estradiol/norethindrone

BMS CW189921  
Ethinyl estradiol; Ethynodiol  
diacetate  
Ethinyl estradiol; Levonorgestrel  
Ethinyl estradiol; Norethindrone  
Ethinyl estradiol; Norethindrone  
acetate  
Ethinyl estradiol; Norgestimate  
Ethinyl estradiol; Norgestrel  
Etidronate disodium  
Etodolac  
Etoposide  
etoricoxib  
exendin-4  
famciclovir

Famotidine  
Felodipine  
fenofibrate  
fenretinide  
Fentanyl

fexofenadine hydrochloride  
filgrastim SD01  
finasteride  
flecainide acetate  
fluconazole

Fludrocortisone acetate  
flumazenil  
Fluoxetine  
Flutamide

fluvastatin  
Fluvoxamine maleate

follitropin alfa/beta  
Formoterol  
Fosinopril  
fosphenytoin sodium  
Furosemide  
Gabapentin  
gadodiamide  
gadopentetate dimeglumine  
gadoteridol  
ganaxolone  
ganciclovir  
gantofiban  
gastrin CW17 immunogen  
gemcitabine hydrochloride

Gemfibrozil

Gentamicin Isoton  
gepirone hydrochloride  
glatiramer acetate

glimepiride  
Glipizide  
Glucagon HCL  
Glyburide  
granisetron hydrochloride

Haloperidal  
BMS 284756  
Hydrochlorothiazid  
Hydrochlorothiazide; Triamterene  
Hydromorphone HCL  
Hydroxychloroquine sulfate  
Ibuprofen  
Idarubicin HCL  
ilodecakin  
ilomastat  
imiglucerase  
Imipramine HCL  
indinavir sulfate  
infliximab  
insulin lispro  
interferon alfacon-1  
interferon beta-1a

interleukin-2  
iodixanol

iopromide  
loxaglate meglumine; loxaglate  
sodium  
Ipratropium  
Irbesartan  
irinotecan hydrochloride  
Isosorbide Dinitrate  
Isotretinoin  
Isradipine  
itasetron  
Itraconazole  
Ketoconazole  
Ketoprofen  
Ketorolac  
Ketotifen  
Labetalol HCL  
lamivudine  
lamivudine; zidovudine  
lamotrigine  
lansoprazole  
lansoprazole, amoxicillin,  
clarithromycin  
leflunomide  
lesopitron  
Leuprolide acetate  
levocarnitine  
levocetirizine  
Levofloxacin  
Levothyroxine  
lintuzumab  
Lisinopril  
lisinopril; hydrochlorothiazide  
CS 834  
Loperamide HCL  
Loracarbef  
loratadine  
Lorazepam  
losartan potassium  
  
losartan potassium;  
hydrochlorothiazide  
Lovastatin  
marimastat  
mecasermin  
Medroxyprogesterone Acetate  
mefloquine hydrochloride  
megestrol acetate  
CVT CW124  
Mercaptopurine  
Meropenem

mesalamine

mesna

Metaxalone

Metfomin

EM 800

Methylphenidate HCL

Methylprednisolone Acetate

FK 463

Metolazone

metoprolol succinate

MK 826

Metronidazole

milrinone lactate

Minocycline HCL

mirtazapine

Misoprostol

mitiglinide

mitoxantrone hydrochloride

mivacurium chloride

modafinil

moexepiril hydrochloride

montelukast sodium

Morphine Sulfate

Mycophenolate mofetil

nabumetone

Nadolol

Naproxen sodium

naratriptan hydrochloride

nefazodone hydrochloride

nelarabine

nelfinavir mesylate

nesiritide

nevirapine

nifedipine

nimodipine

nisoldipine

nitrofurantoin, nitrofurantoin,

macrocrystalline

Nitroglycerin

nizatidine

norastemizole

Norethindrone

norfloxacin

Nortriptyline HCL

octreotide acetate



Oxycodone/APAP  
ofloxacin  
olanzapine  
Omeprazole  
ondansetron hydrochloride  
oprelvekin  
orlistat  
Orphenadrine citrate  
Oxaprozin  
Oxazepam  
oxybutynin chloride  
Oxycodone HCL  
GM 611  
M-CSF  
pagoclone  
palivizumab  
pamidronate disodium  
paricalcitol  
paroxetine hydrochloride  
pemetrexed  
Pemoline  
penicillin V  
pentosan polysulfate sodium  
Pentoxifylline  
Pergolide  
NE 0080  
Phenobarbital  
Phenytoin sodium  
pioglitazone hydrochloride  
Piperacillin sodium  
pleconaril  
poloxamer CW188  
posaconazole  
NN 304  
pramipexole dihydrochloride  
pravastatin sodium  
Prednisone  
pregabalin  
Primidone  
prinomastat  
Prochlorperazine maleate  
Promethazine HCL  
PD 135158  
Propoxyphene-N/APAP  
Propranolol HCL  
prourokinase  
quetiapine fumarate  
quinapril hydrochloride  
rabeprazole sodium  
raloxifene hydrochloride

Ramipril  
Ranitidine  
ranolazine hydrochloride  
relaxin  
remacemide  
repaglinide  
repinotan  
ribavirin+peginterferon alfa-2b  
riluzole  
Rimantadine HCL  
risperidone  
ritonavir  
rizatriptan benxoate  
rocuronium bromide  
rofecoxib  
ropinirole hydrochloride  
rosiglitazone maleate  
Goserelin  
rubitecan  
sagramostim  
saquinavir  
Docetaxel  
satraplatin  
Selegiline HCL  
sertraline hydrochloride  
sevelamer hydrochloride  
sevirumab  
sibutramine hydrochloride  
sildenafil citrate  
simvastatin  
sinapultide  
sitafloracin  
sodium polystyrene sulfonate  
Sotalol HCL  
sparfosic acid  
Spironolactone  
stavudine  
sucralfate  
sumatriptan  
tabimorelin  
tamoxifen citrate  
tamsulosin hydrochloride  
Temazepam  
tenofovir disoproxil  
tepoxalin  
Terazosin HCL  
terbinafine hydrochloride  
terbutaline sulfate  
teriparatide  
tetracycline

thalidomide  
Theophylline  
Thiotepa  
thrombopoetin, TPO  
tiagabine hydrochloride  
ticlopidine hydrochloride  
tifacogin  
tirapazamine  
tirofiban hydrochloride  
tizanidine hydrochloride  
Tobramycin sulfate  
tolterodine tartrate  
tomoxetine  
topiramate  
Topotecan HCL  
toresemide  
tPA analogue  
Tramadol HCL  
trandolapril  
trastuzumab  
Trazadone HCL  
Triamterene/HCTZ  
troglitazone  
trovafloxacin mesylate  
urokinase  
Ursodiol  
valacyclovir hydrochloride  
valdecoxib  
Valproic Acid  
valsartan, hydrochlorothiazide  
valspodar  
Vancomycin HCL  
Vecuronium bromide  
venlafaxine hydrochloride  
Verapamil HCL  
vinorelbine tartrate  
Vitamin B12  
Vitamin C  
voriconazole  
Warfarin Sodium  
xaliproden  
zafirlukast  
zaleplon  
zenarestat  
zidovudine  
zolmitriptan  
Zolpidem  
bleomycin  
Phytoseterol

paclitaxel  
Flutiasone  
Fluorouracil  
Pseudoephedrine  
A 78773  
AGI 1067  
BCX CW1812  
BMS CW188667  
BMS CW193884  
BMS CW204352  
BPI 21  
CD11a  
CEB 925  
Propofol  
GT 102279  
Recombinant hepatitis vaccine  
L 159282  
LFA3TIP  
Daily Multi Vit  
Erythromycin/Sulfax  
Ethinyl estradiol; Desogestrel  
Lithium Carbonate  
LYM 1  
Methylprednisolone                      Sodium  
succinate  
rotavirus vaccine  
saquinavir mesylate  
arginine  
heparin  
Thymosin alpha  
montelukast                      sodium                      and  
fexofenadine hydrochloride  
Iodothyronine  
Iodothyronine and thyroxine  
Codeine  
Ethylmorphine  
Diacetylmorphine  
Hydromorphone  
Hydrocodone  
Oxymorphone  
Dihydrocodeine  
Dihydromorphone  
Methyldihydromorphinone  
Codeine and promethazine  
Codeine,                      phenylephrine                      and  
promethazine  
Codeine and guaifenesin  
Codeine,                      guaifenesin                      and  
pseudoephedrine  
Aspirin, carisoprodol and codeine

Himatropine methylbromide and  
hydrocodone bitartrate  
Hydrocodone bitartrate and  
phenylpropanolamine  
Acetaminophen and hydrocodone  
bitartrate  
Chlorpheniramine maleate,  
hydrocodone bitartrate and  
pseudoephedrine  
Guaifenesin and hydrocodone  
Ibuprofen and hydrocodone  
Chlorpheniramine polistirex and  
hydrocodone polystirex  
naltrexone

Preferably, the polypeptide is (i) an oligopeptide, (ii) a homopolymer of one of the twenty naturally occurring amino acids (L or D isomers), or an isomer, analogue, or derivative thereof, (iii) a heteropolymer of two or more naturally occurring amino acids (L or D isomers), or an isomer, analogue, or derivative thereof, (iv) a homopolymer of a synthetic amino acid, (v) a heteropolymer of two or more synthetic amino acids or (vi) a heteropolymer of one or more naturally occurring amino acids and one or more synthetic amino acids.

Proteins, oligopeptides and polypeptides are polymers of amino acids that have primary, secondary and tertiary structures. The secondary structure of the protein is the local conformation of the polypeptide chain and consists of helices, pleated sheets and turns. The protein's amino acid sequence and the structural constraints on the conformations of the chain determine the spatial arrangement of the molecule. The folding of the secondary structure and the spatial arrangement of the side chains constitute the tertiary structure.

Proteins fold because of the dynamics associated between neighboring atoms on the protein and solvent molecules. The thermodynamics of protein folding and

unfolding are defined by the free energy of a particular condition of the protein that relies on a particular model. The process of protein folding involves, amongst other things, amino acid residues packing into a hydrophobic core. The amino acid side chains inside the protein core occupy the same volume as they do in amino acid  
5 crystals. The folded protein interior is therefore more like a crystalline solid than an oil drop and so the best model for determining forces contributing to protein stability is the solid reference state.

The major forces contributing to the thermodynamics of protein folding are Van der Waals interactions, hydrogen bonds, electrostatic interactions,  
10 configurational entropy and the hydrophobic effect. Considering protein stability, the hydrophobic effect refers to the energetic consequences of removing apolar groups from the protein interior and exposing them to water. Comparing the energy of amino acid hydrolysis with protein unfolding in the solid reference state, the hydrophobic effect is the dominant force. Hydrogen bonds are established during the protein fold  
15 process and intramolecular bonds are formed at the expense of hydrogen bonds with water. Water molecules are “pushed out” of the packed, hydrophobic protein core. All of these forces combine and contribute to the overall stability of the folded protein where the degree to which ideal packing occurs determines the degree of relative stability of the protein. The result of maximum packing is to produce a center of  
20 residues or hydrophobic core that has maximum shielding from solvent.

Since it is likely that lipophilic drugs would reside in the hydrophobic core of a peptide, it would require energy to unfold the peptide before the drug can be released. The unfolding process requires overcoming the hydrophobic effect by hydrating the amino acids or achieving the melting temperature of the protein. The

heat of hydration is a destabilization of a protein. Typically, the folded state of a protein is favored by only 5-15 kcal/mole over the unfolded state. Nonetheless, protein unfolding at neutral pH and at room temperature requires chemical reagents. In fact, partial unfolding of a protein is often observed prior to the onset of irreversible chemical or conformation processes. Moreover, protein conformation generally controls the rate and extent of deleterious chemical reactions.

Conformational protection of active agents by proteins depends on the stability of the protein's folded state and the thermodynamics associated with the agent's decomposition. Conditions necessary for the agent's decomposition should be different than for protein unfolding.

Selection of the amino acids will depend on the physical properties desired. For instance, if increase in bulk or lipophilicity is desired, then the carrier polypeptide will be enriched in the amino acids in the table provided below. Polar amino acids, on the other hand, can be selected to increase the hydrophilicity of the polypeptide.

Ionizing amino acids can be selected for pH controlled peptide unfolding. Aspartic acid, glutamic acid and tyrosine carry a neutral charge in the stomach, but will ionize upon entry into the intestine. Conversely, basic amino acids, such as histidine, lysine and arginine, ionize in the stomach and are neutral in an alkaline environment.

Other factors such as  $\pi$ - $\pi$  interactions between aromatic residues, kinking of the peptide chain by addition of proline, disulfide crosslinking and hydrogen bonding can all be used to select the optimum amino acid sequence for a given application. Ordering of the linear sequence can influence how these interactions can be

maximized and is important in directing the secondary and tertiary structures of the polypeptide.

Furthermore, amino acids with reactive side chains (e.g., glutamic acid, lysine, aspartic acid, serine, threonine and cysteine) can be incorporated for attaching  
5 multiple active agents or adjuvants to the same carrier peptide. This is particularly useful if a synergistic effect between two or more active agents is desired.

As stated above, variable molecular weights of the carrier compound can have profound effects on the active agent release kinetics. As a result, low molecular weight active agent delivery systems are preferred. An advantage of this invention is  
10 that chain length and molecular weight of the polypeptide can be optimized depending on the level of conformational protection desired. This property can be optimized in concert with the kinetics of the first order release mechanism. Thus, another advantage of this invention is that prolonged release time can be imparted by increasing the molecular weight of the carrier polypeptide. Another, significant  
15 advantage of the invention is that the kinetics of active agent release is primarily controlled by the enzymatic hydrolysis of the key bond between the carrier peptide and the active agent.

Dextran is the only polysaccharide known that has been explored as a macromolecular carrier for the covalent binding of drug for colon specific drug  
20 delivery. Generally, it was only possible to load up to 1/10 of the total drug-dextran conjugate weight with drug. As stated earlier, polysaccharides are digested mainly in the colon and drug absorption is mainly limited to the colon. As compared to dextran, this invention has two major advantages. First, peptides are hydrolyzed by any one of several aminopeptidases found in the intestinal lumen or associated with the brush-



border membrane and so active agent release and subsequent absorption can occur in the jejunum or the ileum. Second, the molecular weight of the carrier molecule can be controlled and, thus, active agent loading can also be controlled.

As a practical example, the following table lists the molecular weights of lipophilic amino acids (less one water molecule) and selected analgesics and vitamins.

TABLE 2

<u>Amino acid</u>	<u>MW</u>	<u>Active agent</u>	<u>MW</u>
Glycine	57	Acetaminophen	151
Alanine	71	Vitamin B <sub>6</sub> (Pyroxidine)	169
Valine	99	Vitamin C (Ascorbic acid)	176
Leucine	113	Aspirin	180
Isoleucine	113	Ibuprofen	206
Phenylalanine	147	Retinoic acid	300
Tyrosine	163	Vitamin B <sub>2</sub> (Riboflavin)	376
		Vitamin D <sub>2</sub>	397
		Vitamin E (Tocopherol)	431

Lipophilic amino acids are preferred because conformational protection through the stomach is important for the selected active agents, which were selected based on ease of covalent attachment to an oligopeptide. Eighteen was subtracted from the amino acid's molecular weight so that their condensation into a polypeptide is considered. For example, a decamer of glycine (MW=588) linked to aspirin would have a total molecular weight of 750 and aspirin would represent 24% of the total weight of the active agent delivery composition or over two times the maximum drug loading for

dextran. This is only for an N- or C- terminus application, for those active agents attached to pendant groups of decaglutamic acid, for instance, a drug with a molecular weight of 180 could conceivably have a loading of 58%, although this may not be entirely practical.

- 5           The alcohol, amine or carboxylic acid group of the active agent is covalently attached to the N-terminus, the C-terminus or the side chain of the oligopeptide or polypeptide. The location of attachment depends somewhat on the functional group selection. For instance, if the active drug is a carboxylic acid (e.g., aspirin) then the N-terminus of the oligopeptide is the preferred point of attachment as shown in Fig. 1.
- 10   If the active agent is an amine (e.g., ampicillin), then the C-terminus is the preferred point of attachment in order to achieve a stable peptide linked active agent as shown in Fig. 2. In both, the C- and N-terminus examples, the peptide is, in essence, extended by one monomeric unit forming a new peptide bond. If the active agent is an alcohol, then either the C-terminus or the N-terminus is the preferred point of
- 15   attachment in order to achieve a stable composition. As in the example above where the alcohol, norethindrone, was covalently attached to poly(hydroxypropylglutamine), an alcohol can be converted into an alkylchloroformate with phosgene. This invention, then, pertains to the reaction of this key intermediate with the N-terminus of the peptide carrier as shown in Fig. 3. Figs. 1 through 3 also depict the release of
- 20   the active ingredient from the peptide carrier by intestinal peptidases.

The alcohol can be selectively bound to the gamma carboxylate of glutamic acid and then this conjugate covalently attached to the C-terminus of the peptide carrier. Because the glutamic acid-drug conjugate can be considered a dimer, this product adds two monomeric units to the C-terminus of the peptide carrier where the

glutamic acid moiety serves as a spacer between the peptide and the drug as shown in Fig. 4. Intestinal enzymatic hydrolysis of the key peptide bond releases the glutamic acid-drug moiety from the peptide carrier. The newly formed free amine of the glutamic acid residue will then undergo an intramolecular transamination reaction, thereby, releasing the active agent with coincident formation of pyroglutamic acid as shown in Fig. 5. Alternatively, the glutamic acid-drug dimer can be converted into the gamma ester of glutamic acid N-carboxyanhydride. This intermediate can then be polymerized, as described above, using any suitable initiator as shown in Fig. 4. The product of this polymerization is polyglutamic acid with active ingredients attached to multiple pendant groups. Hence, maximum drug loading of the carrier peptide can be achieved. In addition, other amino acid-NCA's can be copolymerized with the gamma ester glutamic acid NCA to impart specific properties to the drug delivery system.

The invention also provides a method of imparting the same mechanism of action for other polypeptides containing functional side chains. Examples include, but are not limited to, polylysine, polyasparagine, polyarginine, polyserine, polycysteine, polytyrosine, polythreonine and polyglutamine. The mechanism can translate to these polypeptides through a spacer or linker on the pendant group, which is terminated, preferably, by the glutamic acid-drug dimer. This carrier peptide-drug conjugate is distinguished from the prior art by virtue of the fact that the primary release of the drug moiety relies on peptidases and not on esterases. Alternatively, the active agent can be attached directly to the pendant group where some other indigenous enzymes in the alimentary tract can affect release.

The active agent can be covalently attached to the N-terminus, the C-terminus or the side chain of the polypeptide using known techniques. Examples of linking organic compounds to the N-terminus type of a peptide include, but are not limited to, the attachment of naphthylacetic acid to LH-RH, coumarinic acid to opioid peptides and 1,3-dialkyl-3-acyltriazines to tetragastrin and pentagastrin. As another example, there are known techniques for forming peptide linked biotin and peptide linked acridine.

The polypeptide carrier can be prepared using conventional techniques. A preferred technique is copolymerization of mixtures of amino acid N-carboxyanhydrides. Alternatively, if a specific sequence is desired, a solid state automated peptide synthesizer can be used.

The addition of stabilizers to the composition has the potential of stabilizing the polypeptide further. Stabilizers such as sugar, amino acids, polyethylene glycol (PEG) and salts have been shown to prevent protein unfolding. In another embodiment of the invention, a pre-first order release of the active agent is imparted by microencapsulating the carrier polypeptide-active agent conjugate in a polysaccharide, amino acid complex, PEG or salts.

There is evidence that hydrophilic compounds are absorbed through the intestinal epithelia efficiently via specialized transporters. The entire membrane transport system is intrinsically asymmetric and responds asymmetrically to cofactors. Thus, one can expect that excitation of the membrane transport system will involve some sort of specialized adjuvant resulting in localized delivery of active agents. There are seven known intestinal transport systems classified according to the physical properties of the transported substrate. They include the amino acid,

oligopeptide, glucose, monocarboxic acid, phosphate, bile acid and the P-glycoprotein transport systems and each has its own associated mechanism of transport. The mechanisms can depend on hydrogen ions, sodium ions, binding sites or other cofactors. The invention also allows targeting the mechanisms for intestinal epithelial transport systems to facilitate absorption of active agents.

In another embodiment of the invention, the composition includes one or more adjuvants to enhance the bioavailability of the active agent. Addition of an adjuvant is particularly preferred when using an otherwise poorly absorbed active agent. Suitable adjuvants, for example, include: papain, which is a potent enzyme for releasing the catalytic domain of aminopeptidase-N into the lumen; glycorecognizers, which activate enzymes in the BBM; and bile acids, which have been attached to peptides to enhance absorption of the peptides.

Preferably, the resultant peptide-active agent conjugate is formulated into a tablet using suitable excipients and can either be wet granulated or dry compressed.

Compositions of the invention are, in essence, the formation of amides from acids and amines and can be prepared by the following examples.

### **Acid/N-terminus conjugation (Fig. 1)**

An acid bioactive agent can be dissolved in DMF under nitrogen and cooled to 0 °C. The solution can then be treated with diisopropylcarbodiimide and hydroxybenzotriazole followed by the amine peptide carrier. The reaction can then be stirred for several hours at room temperature, the urea by-product filtered off, the product precipitated out in ether and purified using gel permeation chromatography (GPC) or dialysis.

### **Amine/C-terminus conjugation (Fig. 2)**

The peptide carrier can be dissolved in DMF under nitrogen and cooled to 0 °C. The solution can then be treated with diisopropylcarbodiimide and hydroxybenzotriazole followed by the amine bioactive agent. The reaction can then be stirred for several hours at room temperature, the urea by-product filtered off, the product precipitated out in ether and purified using GPC or dialysis.

### **Alcohol/N-Terminus Conjugation (Fig. 3)**

In the following example the combination of the alcohol with triphosgene produces a chloroformate, which when reacted with the N-terminus of the peptide produces a carbamate. Pursuant to this, an alcohol bioactive agent can be treated with triphosgene in dry DMF under nitrogen. The suitably protected peptide carrier is then added slowly and the solution stirred at room temperature for several hours. The product is then precipitated out in ether. The crude product is suitably deprotected and purified using GPC.

Other solvents, activating agents, cocatalysts and bases can be used. Examples of other solvents include dimethylsulfoxide, ethers such as tetrahydrofuran

or chlorinated solvents such as chloroform. Examples of other activating agents include dicyclohexylcarbodiimide or thionyl chloride. An example of another cocatalyst is N-hydroxysuccinimide. Examples of bases include pyrrolidinopyridine, dimethylaminopyridine, triethylamine or tributylamine.

## 5 Preparation of $\gamma$ -Alkyl Glutamate (Fig. 4)

There have been over 30 different  $\gamma$ -alkyl glutamates prepared any one of which may be suitable for the drug alcohol of choice. For example, a suspension of glutamic acid, the alcohol and concentrated hydrochloric acid can be prepared and heated for several hours. The  $\gamma$ -alkyl glutamate product can be precipitated out in acetone, filtered, dried and recrystallized from hot water.

## $\gamma$ -Alkyl Glutamate/C-Terminus Conjugation (Fig. 4)

The peptide carrier can be dissolved in DMF under nitrogen and cooled to 0 °C. The solution can then be treated with diisopropylcarbodiimide and hydroxybenzotriazole followed by the  $\gamma$ -alkyl glutamate bioactive agent. The reaction can then be stirred for several hours at room temperature, the urea by-product filtered off, the product precipitated out in ether and purified using GPC or dialysis.

## Preparation of $\gamma$ -Alkyl Glutamate-NCA

$\gamma$ -Alkyl glutamate can be suspended in dry THF where triphosgene is added and the mixture refluxed under a nitrogen atmosphere until the mixture becomes homogenous. The solution can be poured into heptane to precipitate the NCA product, which is filtered, dried and recrystallized from a suitable solvent.

## **Preparation of Poly[ $\gamma$ -Alkyl Glutamate]**

$\gamma$ -Alkyl glutamate-NCA can be dissolved in dry DMF where a catalytic amount of a primary amine can be added to the solution until it becomes viscous (typically overnight). The product can be isolated from the solution by pouring it into  
5 water and filtering. The product can be purified using GPC or dialysis.

### **EXAMPLE 1**

#### **Preparation of Capped Iodothyronine Composition Comprising a Copolymer of T<sub>3</sub> and T<sub>4</sub> Covalently Attached to the N-terminus of Polyglutamic Acid**

10 The synthesis of polyglutamic acid is well known through a variety of reported methods. For the present examples polyglutamic acid was synthesized through the activation of the Benzyl Glutamic NCA (BnGlu-NCA) monomer. The BnGlu-NCA was then polymerized and the benzyl groups removed with hydrogen bromide. When capping polyglutamic acid, the liberation of its N-terminus amino group from the  
15 hydrogen bromide complex without imparting unwanted nucleophilicity to the free carboxylic acids is critical. Reactions using sodium carbonate, sodium bicarbonate, and sodium acetate produced glutamic acid/T<sub>4</sub>/T<sub>3</sub> copolymer with the T<sub>4</sub> and T<sub>3</sub> incorporation decreasing with increasing pK<sub>b</sub>. Sodium acetate was the preferred reagent because its pK<sub>b</sub> is between that of sodium bromide, polyglutamic acid, and  
20 sodium salt. The reaction using basic alumina kept the T<sub>4</sub>-NCA and T<sub>3</sub>-NCA intact with no apparent capping or self-polymerization. The stability of T<sub>4</sub>-NCA and T<sub>3</sub>-NCA will influence how glutamic acid/T<sub>4</sub>/T<sub>3</sub> copolymer will be commercially manufactured. Sodium acetate can be replaced with sodium carbonate, sodium bicarbonate, sodium propionate, sodium butyrate, sodium pivalate, basic alumina, or



any other weak base capable of neutralizing hydrogen bromide complexed with an amino group.

The synthesis of glutamic acid/T<sub>4</sub>/T<sub>3</sub> copolymer began with benzylglutamic acid, thyroxine, and triiodothyronine. Each of these synthons was independently  
5 reacted with triphosgene in a suitable organic solvent. The BnGlu-NCA was polymerized in tetrahydrofuran (THF) with sodium methoxide as an initiator. Polybenzylglutamic acid was deprotected with 15% hydrogen bromide in acetic acid. This product needs to be free of uncomplexed hydrogen bromide where it was dissolved in DMF and treated with sodium acetate. The previously prepared T<sub>4</sub>-NCA  
10 and T<sub>3</sub>-NCA were blended and added to the solution. The reaction was then stirred until T<sub>4</sub>-NCA or T<sub>3</sub>-NCA were no longer detected by thin layer chromatography (TLC). The final product was added to water and the precipitate was washed with water and dried *in vacuo* to yield a white amorphous powder.

Experimentation with several weak bases revealed that a variety of sodium  
15 salts of a carboxylic acid work in capping polyglutamic acid. The reaction was tried with sodium propionate, sodium butyrate, and sodium pivalate in lieu of sodium acetate all with essentially the same result.

### **Preparation of benzylglutamic acid-NCA**

Benzylglutamic acid (25 grams) was suspended in 400 mL anhydrous ethyl  
20 acetate under nitrogen. The mixture was heated to reflux where 30 grams of triphosgene was added in six (6) equal portions. The reaction was refluxed for three (3) hours until homogenous. The solution was cooled to room temperature, filtered, and concentrated *in vacuo*. The white powder was recrystallized from 50 mL of hot anhydrous ethyl acetate to yield 17.4 grams (63%) of a white powder.

### **Preparation of T<sub>4</sub>-NCA**

In a round bottom flask fitted with a nitrogen inlet, five grams of thyroxine was stirred with 25 mL of tetrahydrofuran (THF) and 1.3 grams of triphosgene and the mixture refluxed for four (4) hours until homogenous. The solution was cooled to room temperature, and added dropwise to 200 mL of heptane with stirring. The crystals  
5 were filtered and dried *in vacuo* to yield 4.72 grams (91%) of an off-white powder.

### Preparation of T<sub>3</sub>-NCA

In a round bottom flask fitted with a nitrogen inlet, 4.29 grams of triiodothyronine was stirred with 20 mL of tetrahydrofuran (THF) and 1.45 grams of triphosgene and the mixture refluxed for four (4) hours until homogenous. The  
10 solution was cooled to room temperature and added dropwise to 200 ml of heptane with stirring. The liquid was decanted off the yellow gum, which was recrystallized, from anhydrous ethyl acetate and hexanes to yield 2.5 grams (56%) of a white powder that was dried under high vacuum.

### Preparation of polybenzylglutamic acid

15 Benzylglutamic acid (17.4 grams) was dissolved in anhydrous tetrahydrofuran (THF) under nitrogen where 238 mg of sodium methoxide was added portionwise. The solution was stirred for two (2) days with a marked increase in viscosity. The solution was poured into 1.5 L of petroleum ether with stirring. The petroleum ether was decanted off and an additional 1L of petroleum ether was added back. The  
20 mixture was stirred by hand, the petroleum ether was decanted off and the process repeated with 500 mL of petroleum ether. The white solid was air dried and then vacuum dried to yield 14.7 (95%) of a white fluffy paper-like solid.

## Preparation of polyglutamic acid

Acetic acid (10mL) was stirred with 0 mL 30wt% hydrogen bromide (HBr) in acetic acid where 1.96 of polybenzylglutamic acid was added by hand. The mixture was stirred at room temperature for one day and was, then, added to 50 mL of ether.

- 5 The white precipitant was filtered, washed with 4 x 30 mL of ether and dried under a high vacuum to yield 1.11 grams (97%) of a white powder.

## Preparation of glutamic acid/T<sub>4</sub>/T<sub>3</sub> copolymer

Polyglutamic acid (375 mg) was dissolved in dry 3 mL DMF. Sodium acetate (24 mg) was added followed by a blend of 105 mg of T<sub>4</sub>-NCA and 8 mg of T<sub>3</sub>-NCA. The solution was stirred for two (2) days where TLC showed the absence of thyronine starting materials. The solution was poured into 30 mL of water and cooled 10 °C overnight. The precipitant was filtered, washed with water, and dried under high vacuum to yield 413 mg (85%) of light beige powder. The proton NMR revealed a copolymer of T<sub>3</sub> and T<sub>4</sub> covalently attached to the N-terminus of polyglutamic acid, which was virtually completely digested by the pronase enzyme system in two hours.

## EXAMPLE 2

### Preparation of Peptide Polymers

**Polyaspartic acid:** Asp(OtBu) (13mg, 0.07mmol) and Asp(OtBu)-NCA (200mg, 0.93 mmol) were dissolved in anhydrous DMF (5ml), and the solution allowed to stir over night at room temperature under argon. The following morning, 2.5 ml of the reaction mixture was transferred to separate flask (Flask B). T<sub>4</sub>-NCA (27mg, 0.03mmol) was added to the original flask (Flask A), and both solutions were allowed to continue stirring under argon for an additional 24 hours. Polymer was

then precipitated by the addition of water (50ml) to each flask. The resulting solids were collected by filtration and dried over night under vacuum.

The dried Asp(OtBu)<sub>n</sub> (Flask B) and T4-Asp(OtBu)<sub>n</sub> (Flask A) were then dissolved in 95% trifluoroacetic acid in water (3ml) and allowed to stir at room

5 temperature for 2 hours. The deprotected polymers were then precipitated by the addition of ethyl ether (10ml) and then storing the suspension at 4 °C for 2 hours. The respective polymers were then collected by filtration and the solids dried over night under vacuum. This afforded 48mg of Asp<sub>n</sub> (Flask B) and 12mg of T4-Asp<sub>n</sub> (Flask A). MALDI indicated that T4-Asp<sub>n</sub> (Flask A) consisted of a mixture of polymers of  
10 varying lengths: T4-Asp<sub>3-12</sub>.

**Polyserine** and **Polythreonine** were also prepared using this protocol. The serine reaction mixture contained N-methylmorpholine (1.1 equivalents).

Amino acid derivative	Polymer	Isolated	Percent yield	Mass Range
Asp(OtBu)	Asp(OtBu) <sub>n</sub>	48mg	84%	NA
	T4-Asp(OtBu) <sub>n</sub>	12mg	14%	T4-Asp <sub>3-12</sub>
Ser(OtBu)	Ser(OtBu) <sub>n</sub>	73mg	101% <sup>3</sup>	Ser <sub>7-8</sub>
	T4-Ser(OtBu) <sub>n</sub>	50mg	43%	T4-Ser <sub>4-9</sub>
Thr(OtBu)	Thr(OtBu) <sub>n</sub>	29mg	20%	Thr <sub>7-8</sub>
	T4-Thr(OtBu) <sub>n</sub>	66mg	24%	T4-Thr <sub>1-8</sub>

The percent yield was estimated based on the total amino acid content in the original reaction prior to splitting the reaction. The Mass range was determined from MALDI. The yield over 100% could reflect either the presence of salts or uneven distribution when the reaction mixture was split.

HPLC and Pronase experiments indicate little to no free T4 is present in the T4-Asp<sub>3-12</sub>, T4-Ser<sub>4-9</sub> and T4-Thr<sub>1-8</sub> samples, and that T4 is liberated upon digestion.

## N-carboxyanhydrides

N-carboxyanhydrides (NCA's) of the amino acids listed below were prepared using a protocol similar to that reported for glutamic acid. Minor variations in their final workups are noted below.

Amino Acid	Chemical Shift in the NCA			
	α	β	γ	other (OtBu)
Alanine	4.41 (q, 1H)	1.57 (d, 3H)		
Valine	4.20 (d, 1H)	2.28-2.19 (m, 1H)	1.08 (d, 3H) 1.02 (d, 3H)	
Serine (OtBu)	4.58 (m, 1H)	3.62 (dd, 1H) 3.50 (dd, 1H)		1.10 (s, 9H)
Aspartic acid (OtBu)	4.51 (dd, 1H)	2.93 (dd, 1H) 2.73 (dd, 1H)		1.44 (s, 9H)
Glutamic acid (OtBu)	4.34 (dd, 1H)	2.28-2.20 (m, 1H)	2.45 (t, 2H)	1.44 (s, 9H)

2.09-1.99(m, 1H)

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5	<b>Amino Acid</b>	<b>Isolation of NCA</b>
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	Alanine	precipitate with hexanes in 68% yield
	Valine	precipitate with hexanes in 89% yield
10	Serine (OtBu)	suspended in isopropanol and precipitated with hexanes in 83% yield
	Aspartic acid (OtBu)	suspended in isopropanol and precipitated with hexanes in 55% yield
15	Glutamic acid (OtBu)	suspended in isopropanol and precipitated with hexanes in 77% yield

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**EXAMPLE 3**

**Preparation of (Glu)<sub>n</sub>-Cephalexin**

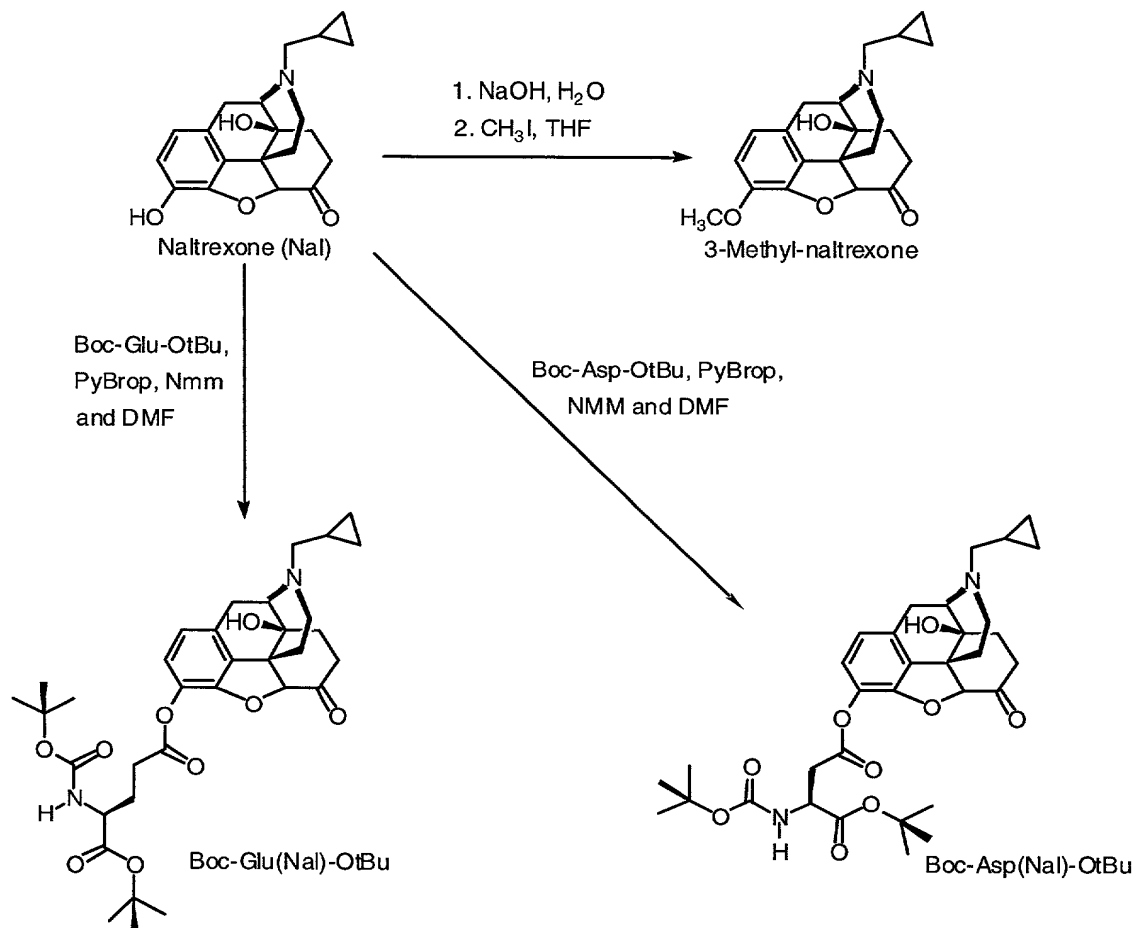
Glu(OtBu)NCA (1.000 g, 4.4mmol) and Cephalexin•HCl (0.106g, 0.3mmol) were dissolved in anhydrous DMF (5ml). The reaction was then allowed to stir at room temperature under argon. After 3 days, the solvent was removed by rotary-  
 evaporation under vacuum. The resulting solid was then placed under argon and then dissolved in 4N HCl in Dioxane (2ml) and then allowed to stir at room temperature under a blanket of argon. After 1 hour, the dioxane and HCl were removed by rotary-  
 evaporation under vacuum. The solid was then suspended in methanol (2ml) and  
 once more brought to dryness by rotary-evaporation in order to remove residual HCl and dioxane. This material was then resuspended in methanol (2ml) and precipitated by the addition of water (20ml). The aqueous suspension was then stored at 4°C for 4

hours, and the solid isolated by centrifugation. The pelleted material was then allowed to dry under vacuum over night. This process afforded a mixture of (Glu)<sub>n</sub> and (Glu)<sub>n</sub>-cephalexin (464mg) as determined by MALDI. MALDI indicates a mixture of polymers (Glu)<sub>7-13</sub> and (Glu)<sub>5-14</sub>-cephalexin. Other chain-lengths may be present but they are not clearly visible in the MALDI spectra. Reversed-phase HPLC (265nm detection, C18 column, 16%MeOH/4%THF/80%water mobile phase) indicated that no free cephalexin was present in the isolated material. "Water" in the HPLC actually refers to an aqueous buffer of 0.1% heptanesulfonic acid and 1.5% triethylamine.

## EXAMPLE 4

### Naltrexone Derivatives:

5



**3-Methyl-naltrexone:** Naltrexone (6.0 g, 16.5 mmol) was dissolved in 100 ml distilled water. The solution was titrated with 1N NaOH to a final pH of 11.8. In the course of the titration, neutral naltrexone precipitated from solution and then went back into solution. Upon reaching pH 11.8, the solvent was removed by rotary-evaporation under high vacuum, and the resulting solid stored under vacuum overnight at room temperature.. The solid was then suspended/dissolved in anhydrous tetrahydrofuran (200 ml) and allowed to stir at room temperature under argon. A solution of iodomethane (2.1 mg, 33 mmol) in 50 ml of tetrahydrofuran was added

10

15



dropwise over the course 30 minutes. The reaction was then allowed to stir an additional 3 hours at room temperature under argon. The solvent was then removed by rotary-evaporation under reduced pressure. The residual solid was then dissolved

5 3x30 ml of 1N NaOH and finally twice more with 30 ml saturated aqueous NaCl.

The organic solution was collected and dried over sodium sulfate. Removal of solvent by rotary-evaporation and drying over night under vacuum afforded pure 3-methylnaltrexone (5.6g, 15.8 mmol, 96% yield) as a brown residue and composition determined by TLC and <sup>1</sup>H-NMR. Features used to identify the compound by

10 comparison to the spectrum of naltrexone: <sup>1</sup>H-NMR (360 MHz, CDCl<sub>3</sub>) δ 6.677 (d, 1H, naltrexone aromatic), 6.591 (d, 1H, naltrexone aromatic), 3.874 (s, 3H, methoxy group.), 0.6-0.5 ppm (m, 2H, naltrexone cyclopropyl) and 0.2-0.1 ppm (m, 2H, naltrexone cyclopropyl).

15 **Boc-Glu(Nal)-OtBu:** The solids Boc-Glu-OtBu (0.96g, 3.18mmol), naltrexone (1.00g, 2.65mmol) and PyBrop (1.73g, 3.71mmol) were dissolved in 5 ml of anhydrous DMF and stirred at room temperature under argon. Dry N-methylmorpholine (1.08ml, 9.81mmol) was added and the reaction allowed to continue stirring at room temperature under argon. After two days additional Boc-

20 Glu-OtBu (0.096g, 0.32mmol), PyBrop (0.173g, 0.37mmol) and N-methylmorpholine (0.10ml, 0.981mmol) were added. After 2 more days, the solvent was removed by rotary-evaporation under high vacuum. The resulting residue was then dissolved in CHCl<sub>3</sub>, and the resulting organic solution extracted with 2x20 ml of saturated NaCl , 3x20 ml of 10% Na<sub>2</sub>CO<sub>3</sub> and a final wash with 20 ml saturated aqueous NaCl. The

25 organic solution was collected, dried over sodium sulfate and then adsorbed onto silica. Pure naltrexone conjugated amino acid (0.486g, 0.78mmol, 29%) was then

isolated by flash chromatography and a gradient of 0-1.5% CH<sub>3</sub>OH in CHCl<sub>3</sub>. The purity of the isolated material was determined by TLC (6:1 CH<sub>3</sub>OH/CHCl<sub>3</sub>), and the presence of both the amino acid moiety and the naltrexone were confirmed by <sup>1</sup>H-

NMR. Indicative protons: <sup>1</sup>H-NMR (360 MHz, CDCl<sub>3</sub>) δ 6.81 (d, 1H, naltrexone

aromatic), 6.63 (d, 1H, naltrexone aromatic), 4.3-4.2 (m, 1H, glutamic acid α-proton),

1.7-1.3 (pair of bs, 18H, Boc and OtBu groups.), 0.6-0.4 ppm (m, 2H, naltrexone

cyclopropyl) and 0.2-0.0 ppm (m, 2H, naltrexone cyclopropyl).

**Boc-Asp(Nal)-OtBu:** Boc-Asp(Nal)-OtBu was obtained in 41% isolate yield using a

similar protocol. Indicative protons: <sup>1</sup>H-NMR (360 MHz, CDCl<sub>3</sub>): δ 6.84 (d, 1H,

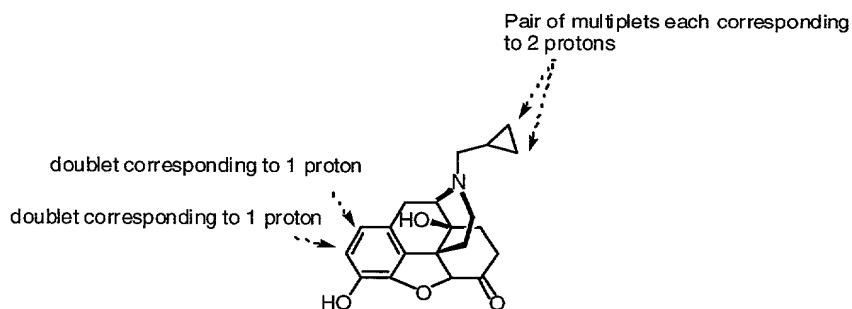
naltrexone aromatic), 6.66 (d, 1H, naltrexone aromatic), 4.6-4.5 (m, 1H, aspartic acid

α-proton), 1.6-1.3 (pair of bs, 18H, Boc and OtBu groups.), 0.7-0.5 ppm (m, 2H,

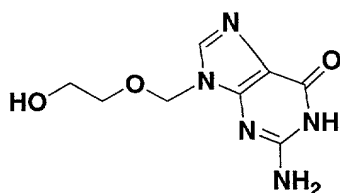
naltrexone cyclopropyl) and 0.4-0.1 ppm (m, 2H, naltrexone cyclopropyl).

### NMR characterization:

While naltrexone has a complex NMR spectrum, there are several key protons that have distinct chemical shifts and are unique to naltrexone.

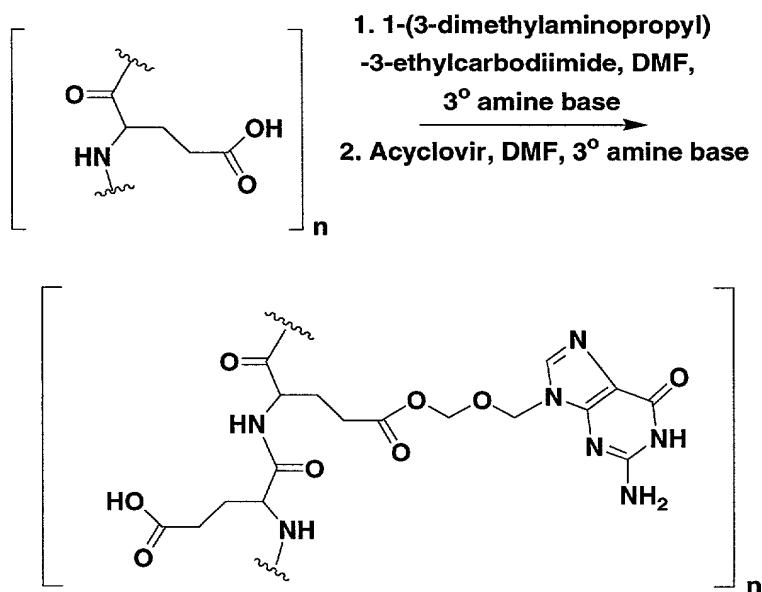


# EXAMPLE 5



Acyclovir

2-Amino-9-(2-hydroxy-ethoxymethyl)-1,9-dihydro-purin-6-one



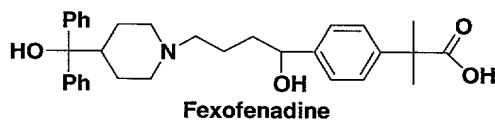
## Poly-Glu(Acyclovir)

To a solution of poly-glu<sub>15</sub> (0.600g, 0.310mmol) in DMF (25ml) was added EDCI (2.07g, 10.8mmol). The resulting mixture was allowed to stir at ambient temperature for one hour. Then, N-methyl morpholine (0.51ml, 4.7mmol) was added followed by a mixture of acyclovir (1.74g, 7.75mmol), DMF (25ml) and N-methyl morpholine (0.85ml). The reaction mixture was stirred at ambient temperature for 4 days. After this, water (50ml) was added and all solvent was removed. To the dried mixture was added water (100ml) and a precipitate of unreacted acyclovir formed.

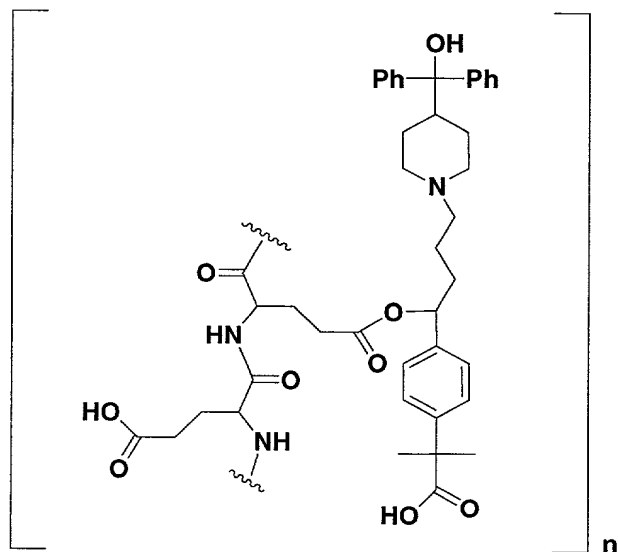
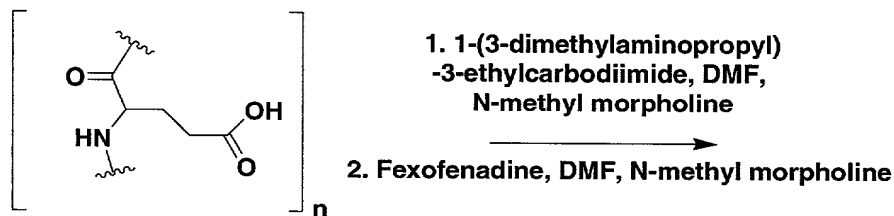
Solid was centrifuged and the supernate was purified using ultrafiltration (YM1

membrane). Approximately 300ml water was allowed to pass through the membrane. NMR has shown an unexpected alkyl-urea side chain attached impurity. Poly-glu(acyclovir) (0.970g) was obtained as a light yellow solid:  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  1.11 (br m, 4H, urea), 2.01 (br m, 2H, Glu- $\beta$  H), 2.39 (br m, 2H, Glu- $\gamma$  H), 2.72 (br m, 2H, urea), 3.32 (br m, 6H, acyclovir  $\text{CH}_2$  and urea), 3.83 (br m, 3H, urea), 4.38 (br d, 3H, Glu- $\alpha$  H), 5.47 (br s, 2H, acyclovir 1'  $\text{CH}_2$ ), 7.94 (br s, 1H, acyclovir 8 CH).

### EXAMPLE 6



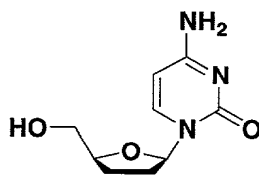
2-(4-[1-Hydroxy-4-[4-(hydroxy-diphenyl-methyl)-piperidin-1-yl]-butyl]-phenyl)-2-methyl-propionic acid



**Poly-Glu(Fexofenadine)**

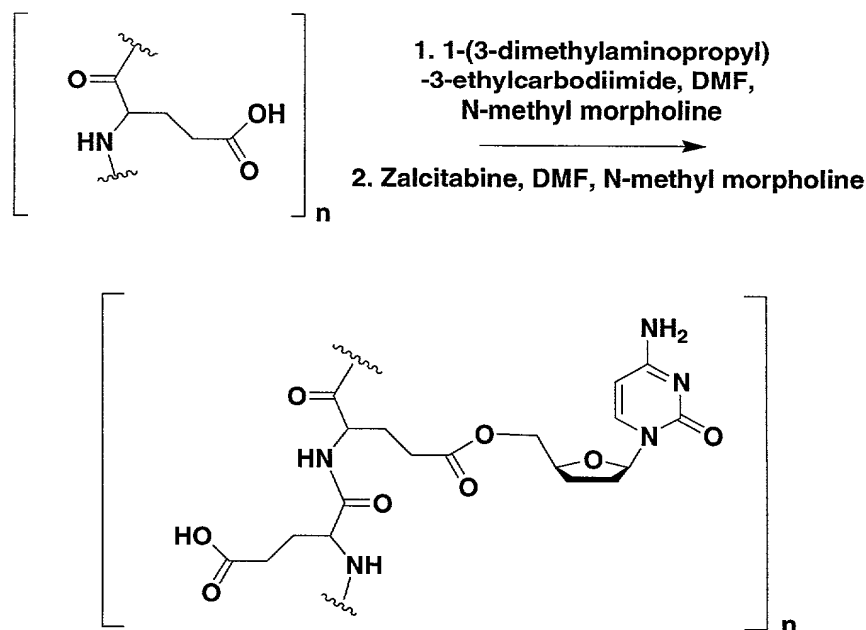
To a solution of poly-glu<sub>15</sub> (0.078g, 0.040mmol) in DMF (5ml) was added EDCI (0.035g, 0.18mmol). After stirring for 30 minutes, N-methyl morpholine was added (0.03ml, 0.24mmol). After stirring for 10 minutes, a solution of fexofenadine (0.100g, 0.20mmol), N-methyl morpholine (0.07ml, 0.60mmol) and DMF (5ml) was added via a syringe. After stirring reaction at ambient temperatures for three days, sample was dissolved in water (25ml). A solid precipitate formed which was both drug-conjugate and free fexofenadine. Water was acidified and all solids dissolved. Purification using ultrafiltration (YM1 followed by YM3) and size exclusion chromatography using Sephadex-25 at pH 7 yielded poly-glu(fexofenadine) (0.010g) as a white solid: <sup>1</sup>H NMR (D<sub>2</sub>O) δ 1.37 (s, 8H, fex. CH<sub>2</sub> and CH<sub>3</sub>), 1.58 (br m, 5H, fex. CH and CH<sub>2</sub>), 1.99 (br m, 24H, Glu-β H), 2.31 (br m, 24H, Glu-γ H), 2.70 (br m, 10H, fex. CH and CH<sub>2</sub>), 4.14 (br m, 26H, Glu-α H), 7.25 (br m, 14H, fex. aromatic H).

#### EXAMPLE 7



**Zalcitabine**

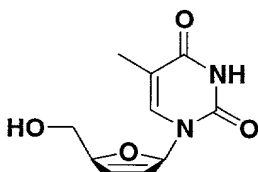
**4-Amino-1-(5-hydroxymethyl-tetrahydro-furan-2-yl)-1H-pyrimidin-2-one**



### Poly-Glu(Zalcitabine)

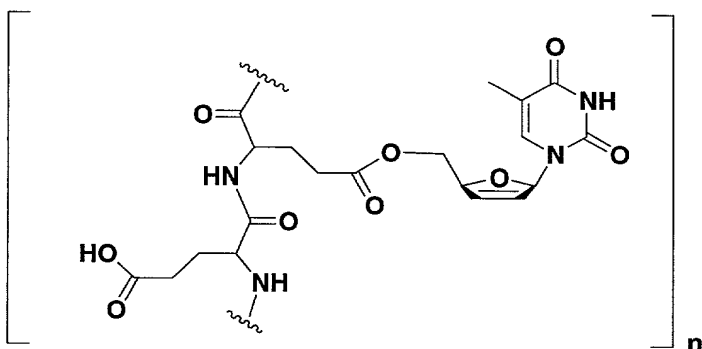
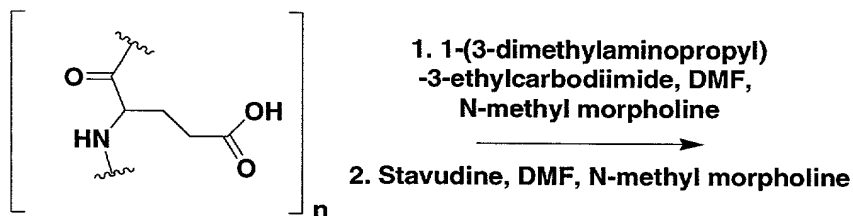
To a solution of poly-glu<sub>15</sub> (0.123g, 0.060mmol) in DMF (8ml) was added EDCI (0.403g, 2.10mmol). After 30 minutes, N-methyl morpholine (0.13ml, 1.2mmol) was added. After 35 minutes, a solution of zalcitabine (0.200g, 0.95mmol), N-methyl morpholine (0.10ml, 0.9mmol) and DMF (2ml) was added via a syringe. The resulting mixture was stirred at ambient temperature for 48 hours. Solvent was removed and the residue was dissolved in water (15ml). Ultrafiltration (YM1 followed with YM3) and size exclusion using Sephadex-25 at pH 7 yielded poly-glu(zalcitabine) (0.083g) as a light yellow solid: <sup>1</sup>H NMR (DMSO-d<sub>6</sub> w/D<sub>2</sub>O) δ 1.14 (br m, 20H, urea), 1.90 (br m, 30H, Glu-β H, Glu-γ H and CH<sub>2</sub> in zalcitabine), 2.66 (br m, 4H, urea), 3.24 (br m, 36H, urea, CH and CH<sub>2</sub> in zalcitabine), 4.29 (br m, 8H, Glu-α H), 5.87 (br s, 1H, zalcitabine 1' CH), 7.18 (br s, 1.19H, zalcitabine NH<sub>2</sub>), 8.52 (br s, 1H, zalcitabine 6 CH).

### EXAMPLE 8



Stavudine

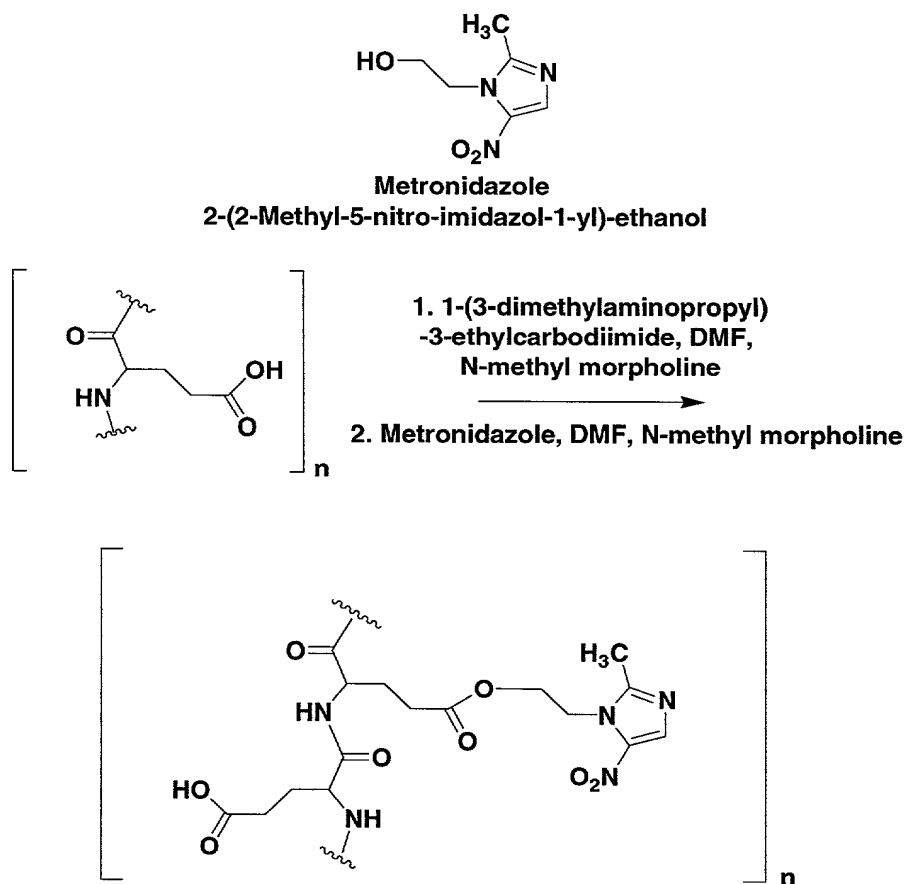
1-(5-Hydroxymethyl-2,5-dihydro-furan-2-yl)-5-methyl-1*H*-pyrimidine-2,4-dione



### Poly-Glu(Stavudine)

Preparation was similar to poly-glu(zalcitabine). Purification using ultrafiltration (YM1) yielded poly-glu(stavudine) (0.089g) as a white solid:  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  1.87 (s, 3H, stavudine 5  $\text{CH}_3$ ), 2.06 (br m, 38H, Glu- $\beta$  H and Glu- $\gamma$  H), 2.49 (br m, 12H, Glu- $\gamma$  H), 3.75 (br m, 12H, urea and stavudine 5'  $\text{CH}_2$ ), 3.96 (br m, 12H, urea), 4.45 (br d, 13H, Glu- $\alpha$  H), 5.98 (d, 1H, stavudine 1' CH), 6.48 (d, 1H, stavudine 3' CH), 6.96 (d, 1H, stavudine 2' CH), 7.63 (s, 1H, stavudine 6 CH).

# EXAMPLE 9

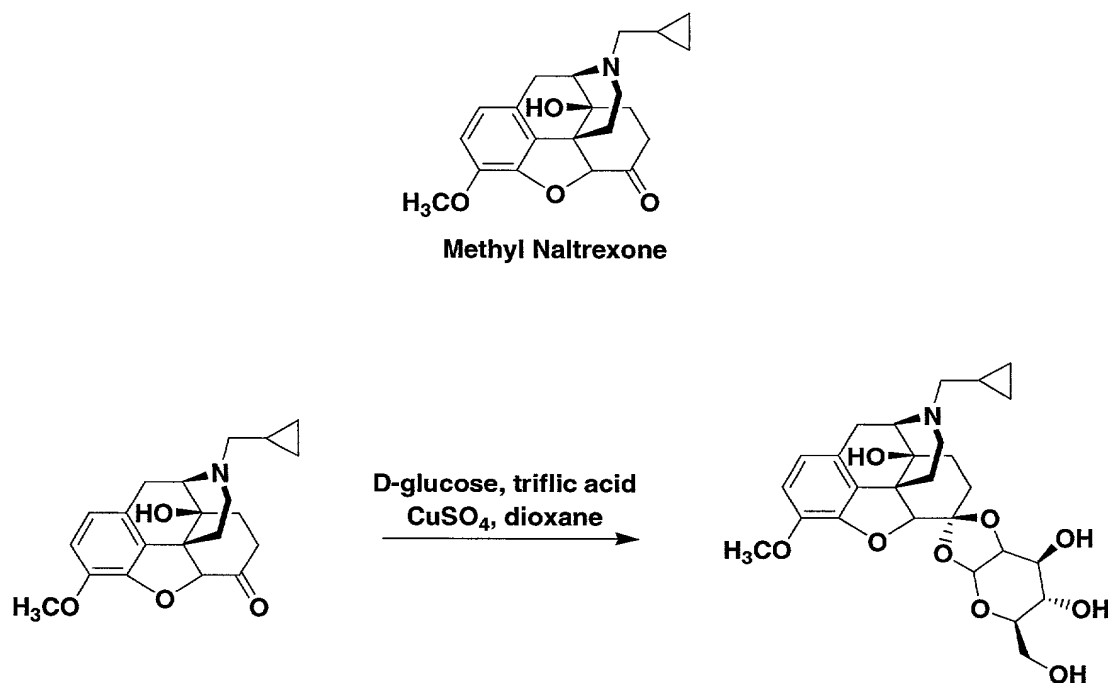


## 5 Poly-Glu(Metronidazole)

Preparation was similar to poly-glu(zalcitabine). Purification using ultrafiltration (YM1) yielded poly-glu(metronidazole) (0.326g) as a yellow solid: <sup>1</sup>H NMR (DMSO-d<sub>6</sub>) δ 1.18 (br d, 13H, urea), 1.93 (br s, 17H, Glu-β H and Glu-γ H), 2.71 (br s, 16H, urea), 4.01 (br m, 18H, Glu-α H and metronidazole CH<sub>2</sub>), 4.58 (br s, 2H, metronidazole CH<sub>2</sub>), 8.05 (br s, 1H, metronidazole 2 CH).



## EXAMPLE 10

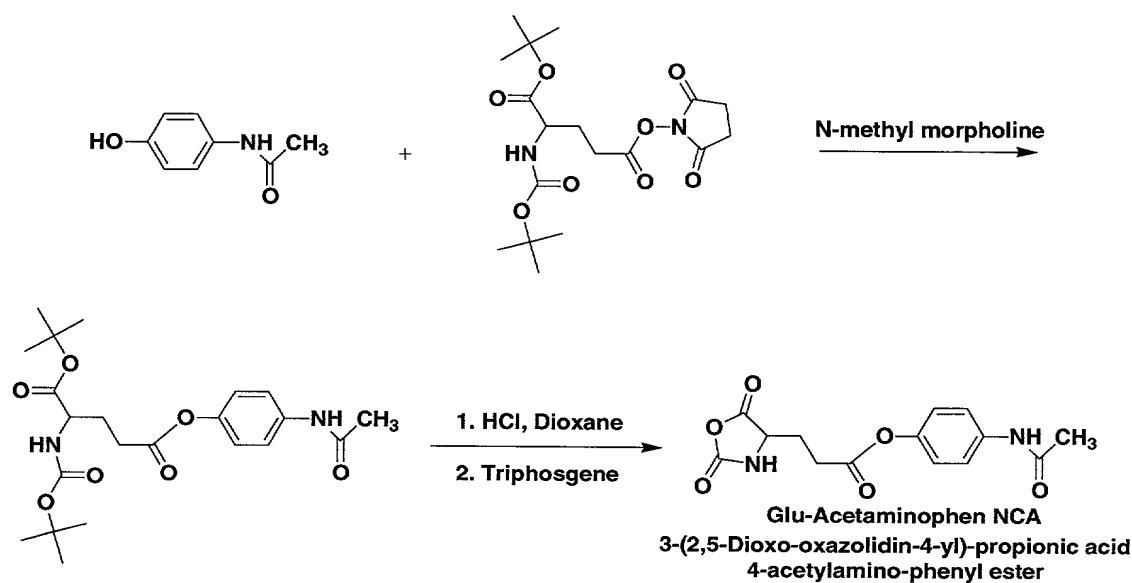
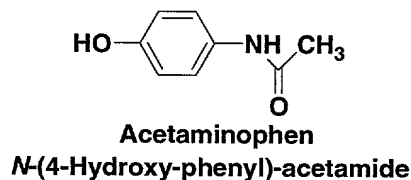


### Methyl Naltrexone – Glucose Ketal Conjugate

To a solution of methyl naltrexone (0.200g, 0.56mmol) in dioxane (20ml) was added D- $\alpha$ -glucose (2.02g, 11.2mmol), triflic acid (0.05ml, 0.62mmol), and CuSO<sub>4</sub> (1.00g). The reaction mixture was stirred at ambient temperatures for 4 days. Reaction was then filtered, neutralized with NaHCO<sub>3</sub> (sat.) and filtered again. Dioxane and water were removed and the residue was taken up in CHCl<sub>3</sub> and extracted with water (3X100ml). The organic layer was dried over MgSO<sub>4</sub> and solvents were removed under reduced pressure. Crude product was purified over silica gel (0-10% MeOH in CHCl<sub>3</sub>) to obtain the ketal conjugate (0.010g) in a 1:1 mixture with free methyl naltrexone: <sup>1</sup>H NMR (CDCl<sub>3</sub>)  $\delta$  0.14 (br s, 4H, naltrexone cyclopropyl), 0.53 (br m, 4H, naltrexone cyclopropyl), 0.90 (m, 2H, naltrexone cyclopropyl), 1.48 (m, 6H, naltrexone), 2.19-2.78 (m, 12H, naltrexone), 3.03 (m, 2H,

naltrexone), 3.75 (q, 2H, glucose), 3.87 (m, 8H, naltrexone CH<sub>3</sub> and glucose), 3.97 (q, 2H, glucose), 4.14 (q, 1H, glucose), 4.33 (t, 1H, glucose), 4.66 (s, 1H, naltrexone), 6.65 (m, 4H, naltrexone).

## EXAMPLE 11



## 2-Amino-pentanedioic acid 5-(4-acetylaminophenyl) ester or Glu(Acetaminophen)

To a solution of Boc-Glu(OSuc)-OtBu (0.500g, 1.25mmol) and acetaminophen (0.944g, 6.25mmol) in THF (15ml) was added N-methyl morpholine (1.40ml, 12.5mmol). The reaction was allowed to heat to reflux and stirred at reflux overnight. Solvent was then removed and the crude compound was purified over silica gel (50-75% ethyl acetate in hexanes) to obtain Boc-Glu(Acetaminophen)-OtBu

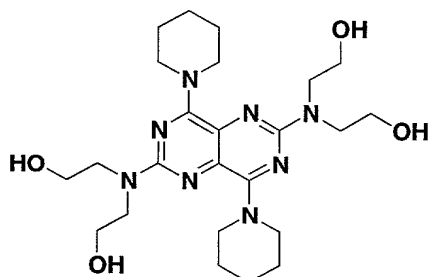
(0.432g, 0.900mmol, 72%):  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.43 (d, 18H, t-Bu), 1.97 (m, 1H, Glu- $\beta$  H), 2.12 (s, 3H, acetaminophen  $\text{CH}_3$ ), 2.25 (m, 1H, Glu- $\beta$  H), 2.60 (m, 2H, Glu- $\gamma$  H), 4.25 (m, 1H, Glu- $\alpha$  H), 7.04 (d, 2H, acetaminophen aromatic), 7.48 (d, 2H, acetaminophen aromatic).

5 A solution of Boc-Glu(Acetaminophen)-OtBu (0.097g, 0.20mmol) in 4N HCl in dioxane (10ml) was stirred at ambient temperatures for 2 hours. Solvent was removed to obtain glu(acetaminophen) (0.90g) as the HCl salt:  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  2.19 (s, 3H, acetaminophen  $\text{CH}_3$ ), 2.41 (m, 2H, Glu- $\beta$  H), 2.97 (t, 2H, Glu- $\gamma$  H), 4.18 (t, 1H, Glu- $\alpha$  H), 7.19 (d, 2H, acetaminophen aromatic), 7.51 (d, 2H, acetaminophen aromatic);  $^{13}\text{C}$  NMR (DMSO)  $\delta$  23.80, 29.25, 51.00, 66.24, 119.68, 121.69, 137.00, 145.35, 168.23, 170.42, 170.79.

### 3-(2,5-Dioxo-oxazolidin-4-yl)-propionic acid 4-acetylaminophenyl ester or Glu(Acetaminophen) NCA

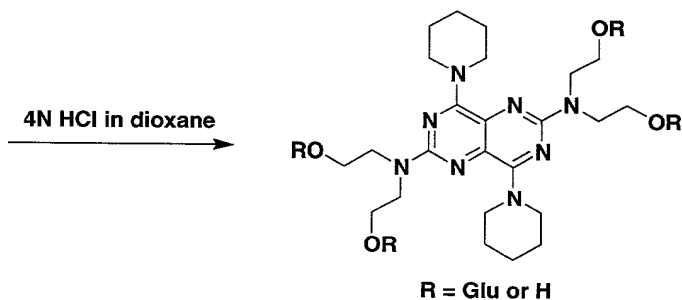
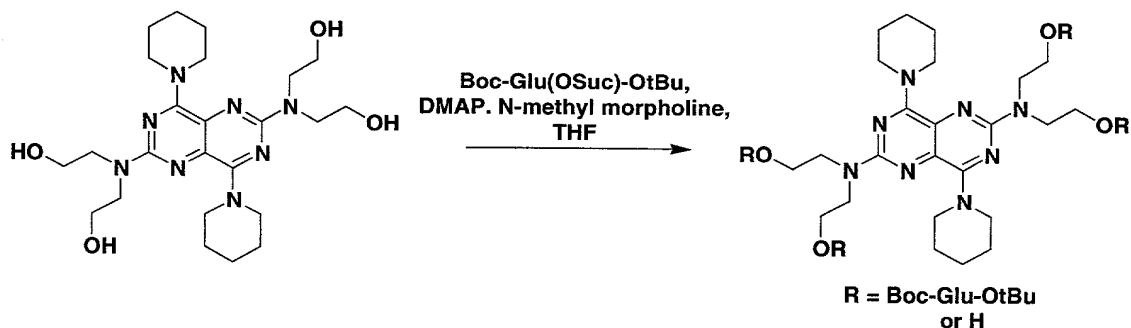
15 To a mixture of 2-amino-pentanedioic acid 5-(4-acetylaminophenyl) ester (1.54g, 4.29mmol) in THF (40ml) was added triphosgene (1.02g, 3.43mmol). The resulting solution was stirred at reflux for 3 hours. During reaction, the product precipitated and was filtered away to obtain the NCA of glu(acetaminophen) (1.02g, 2.64mmol, 62%) as an off white solid:  $^1\text{H}$  NMR ( $\text{DMSO}-d_6$ )  $\delta$  2.01 (s, 3H, acetaminophen  $\text{CH}_3$ ), 2.15 (m, 2H, Glu- $\beta$  H), 2.81 (m, 2H, Glu- $\gamma$  H), 3.76 (t, 1H, Glu- $\alpha$  H), 7.06 (d, 2H, acetaminophen aromatic), 7.63 (d, 2H, acetaminophen aromatic), 8.57 (br s, 1H, amide), 10.19 (s, 1H, amide);  $^{13}\text{C}$  NMR (DMSO)  $\delta$  23.81, 29.25, 52.13, 54.62, 119.66, 121.71, 136.98, 145.35, 167.44, 168.19, 170.46, 170.77.

## EXAMPLE 12



Dipyrimadole

2-[[6-[Bis-(2-hydroxy-ethyl)-amino]-4,8-di-piperidin-1-yl-pyrimido[5,4-*d*]pyrimidin-2-yl]-(2-hydroxy-ethyl)-amino]-ethanol



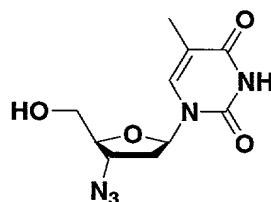
### Glu(Dipyrimadole)

To a solution of dipyrimadole (0.500g, 0.990mmol) and Boc-Glu(OSuc)-OtBu (3.96g, 9.91mmol) in THF (35ml) was added DMAP (0.072g, 0.60mmol) and N-methyl morpholine (0.22ml, 1.98mmol). The solution was then refluxed for 48 hours. Solvent was then removed and crude product was purified over silica gel (25-50% ethyl acetate in hexanes). Two major products were isolated, one with R=2-3 (0.57g)

and another with R=3-4 (2.80g), as bright yellow oils: [for R=2-3  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.41 (s, 42H, t-Bu), 1.64 (br s, 5H, dipyrimadole), 1.85 (m, 2H, Glu- $\beta$  H), 2.07 (m, 2H, Glu- $\beta$  H), 2.37 (m, 4H, Glu- $\gamma$  H), 3.60-4.24 (m, 12H, Glu- $\alpha$  H and dipyrimadole)]; [for R=3-4 similar as above except 1.44 (s, 56H, t-Bu)].

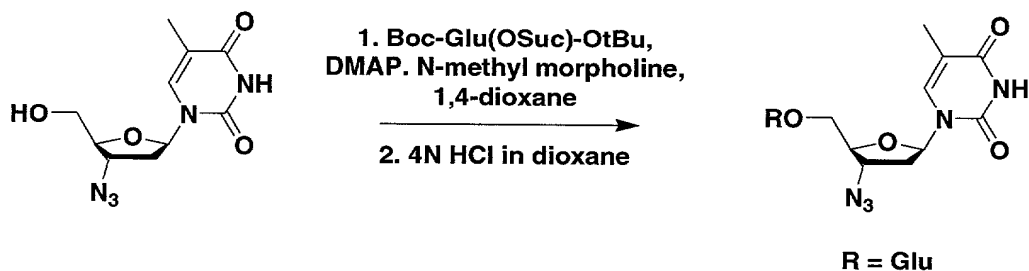
A solution of Boc-Glu(dipyrimadole)-OtBu (R=2-3, 0.57g) and 4N HCl in dioxane (20ml) was stirred at ambient temperature for 2.5 hours. Solvent was removed and the product (0.280g) was a bright yellow solid:  $^1\text{H}$  NMR ( $\text{DMSO-d}_6$ )  $\delta$  1.65 (br m, 4H, Glu- $\beta$  H and dipyrimadole), 2.04 (br m, 2H, Glu- $\beta$  H), 2.40 (br m, 4H, Glu- $\gamma$  H), 3.75 (br m, 8H, dipyrimadole), 3.91 (br m, 2H, Glu- $\alpha$  H), 8.55 (br m, 2H, amide H).

### EXAMPLE 13



Zidovudine (AZT)

1-(4-Azido-5-hydroxymethyl-tetrahydro-furan-2-yl)-5-methyl-1H-pyrimidine-2,4-dione



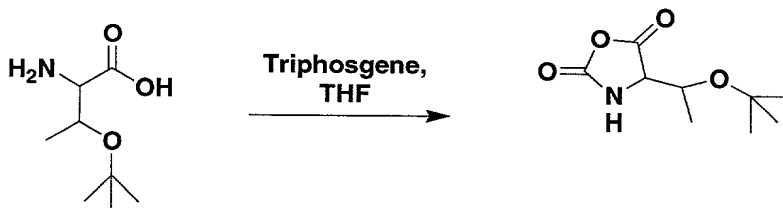
### Glu(AZT)

To a solution of zidovudine (1.00g, 3.75mmol) and Boc-Glu(OSuc)-OtBu (3.00g, 7.49mmol) in dioxane (75ml) was added DMAP (0.137g, 1.13mmol) and N-methyl morpholine (0.82ml, 7.49mmol). The solution was heated to reflux for 6

hours and heated at 70°C for 12 hours. Solvent was then removed and the crude product was purified over silica gel (100%CHCl<sub>3</sub>) to obtain Boc-Glu(AZT)-OtBu (1.09g, 1.91mmol, 51%) as a yellow foam: <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 1.40 (d, 32H, t-Bu), 1.86 (s, 3H, AZT CH<sub>3</sub>), 2.11 (m, 2H, Glu-β H), 2.38 (m, 4H, Glu-γ H and AZT 2' CH<sub>2</sub>), 4.00-4.31 (m, 4H, AZT 4' CH, 5' CH<sub>2</sub> and Glu-α H), 5.21 (d, 1H, AZT 3' CH), 6.01 (t, 1H, AZT 1' CH), 7.16 (s, 1H, AZT 6 CH).

A solution of Boc-Glu(AZT)-OtBu (1.09g, 1.91mmol) in 4N HCl in dioxane (20ml) was stirred for 4 hours and solvent removed. The product, Glu(AZT) (0.89g, 1.99mmol, quant.), was obtained as a yellow glass: <sup>1</sup>H NMR (D<sub>2</sub>O) δ 1.89 (s, 3H, AZT CH<sub>3</sub>), 2.21 (m, 4H, Glu-β H and AZT 2' CH<sub>2</sub>), 2.58 (m, 2H, Glu-γ H), 3.70 (t, 1H, Glu-α H), 4.05-4.41 (m, 4H, AZT 4' CH, 3' CH and 5' CH<sub>2</sub>), 6.18 (t, 1H, AZT 1' CH), 7.51 (s, 1H, AZT 6 CH).

#### EXAMPLE 14



#### Threonine NCA

To a mixture of Thr-OtBu (0.500g, 2.85mmol) in THF (25ml) was added triphosgene (0.677g, 2.28mmol). The resulting solution was stirred at reflux for 3 hours. The solution was evaporated to dryness to obtain Thr-NCA (0.500g, 2.48mmol, 87%) as a white solid. Thr-NCA was used without further characterization.

#### EXAMPLE 15

## **Preparation of a DRUG-GLU conjugate as a starting synthon for polymerization**

With non-primary amine drug candidates, formation of the Drug-poly-Glu conjugate may prove problematic. To overcome this difficulty, the following scheme was used, wherein the drug is first conjugated to Glu, and this synthon is then used to initiate coupling. The protocol has been successfully applied to sertraline and to metoclopramide.

### **Protocol for coupling Boc-Glu(OtBu)-OH to Sertraline**

1. Boc-Glu(OtBu)-OH (0.44 g, 1.46 mmol) and PyBOP (0.84 g, 1.60 mmol) were dissolved in dry DMF (15 mL) with stirring.
2. DIEA (0.31 mL, 1.75 mmol) was added and the amino acid derivative was allowed to activate for 15 minutes.
3. Sertraline hydrochloride (0.50 g, 1.46 mmol) was added to the stirring mixture followed by an additional 0.31 mL DIEA.
4. The mixture was allowed to stir for 16 h.
5. The solution was stripped yielding a brown oil.
6. The oil was dissolved in EtOAc (100 mL) and the resulting solution was washed with 10 % HCl (3 x 30 mL), saturated NaHCO<sub>3</sub>, 4M NaHSO<sub>4</sub>, and brine (2 x 30 mL, respectively).
7. The solution was dried over MgSO<sub>4</sub>, filtered and the solvent was removed by rotary evaporation under reduced pressure, yielding a light brown oil.
8. The oil was dried on the vacuum manifold and the product was purified by column chromatography on silica gel using EtOAc/Hexanes 1:5 to 1:4 solvent system.

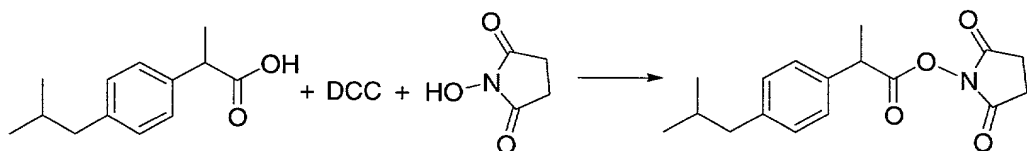
9. The product fractions were pooled and solvent was again removed by rotary evaporation yielding 0.85 g (99%) of the final product, Sertraline-NH-C(O)-Glu-NH<sub>3</sub><sup>+</sup>.

10. The preparation was dried on the vacuum manifold.

## 5 EXAMPLE 16

### Synthesis of Poly-Lysine-Ibuprofen

I. Preparation of Ibuprofen-O-Succinimide (RI-172) (Grafe & Hoffman, *Pharmazie* 55: 286-292, 2000)



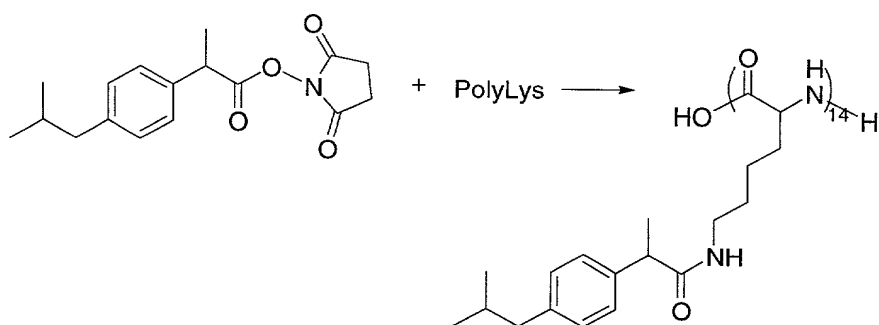
To a stirring solution of ibuprofen (2.06 g, 10 mmol) in 5 mL of dioxane at room temperature was added a solution of dicyclohexylcarbodiimide (DCC, 2.27 g, 11 mmol) in 25 mL of dioxane. After 10 minutes a solution of N-hydroxysuccinimide (NHS, 1.16 g, 10 mmol) in 15 mL of dioxane was added. The reaction mixture was allowed to stir at room temperature for 5 hours and then filtered through a sintered glass funnel to remove the dicyclohexylurea (DCU). After rotary evaporation, the product was crystallized from methylene chloride/hexanes to yield 2.36 g (78%) of a colorless solid. <sup>1</sup>H-NMR (dmsO-d<sub>6</sub>): δ 0.86 (d, 6, CH<sub>3</sub>), 1.49 (d, 3, α-CH<sub>3</sub>), 1.81 (m, 1, CH), 2.43 (d, 2, CH<sub>2</sub>), 3.33 (m, 4, CH<sub>2</sub>CH<sub>2</sub>), 4.22 (q, 1, CH), 7.16 (d, 2, ArH), 7.28 (d, s, ArH).

15

20

25 II. Conjugation of Poly-Lysine with Ibuprofen-O-Succinimide (RI-197)





Poly-lysine-HBr (Sigma, 100 mg, 34.5nmol) was dissolved in 1 mL of water that had brought to a pH of 8 with sodium bicarbonate, and stirred at room temperature. To this solution was added a solution of ibuprofen-O-succinimide (116 mg, 380 nmol) in 2 mL of dioxane. After stirring overnight, the dioxane was removed by rotary evaporation and diluted with 10 mL of pH 8 sodium bicarbonate in water. The precipitated product was filtered through a sintered glass funnel and washed with 3 X 10 mL of water and 4 X 10 mL of diethyl ether. After drying overnight by high vacuum the solid product was scraped out yielding 105 mg (62%). <sup>1</sup>H-NMR (dmso-d<sub>6</sub>): δ 0.85 (br s, 6, CH<sub>3</sub>), 1.27 (br s, 3, α-CH<sub>3</sub>), 1.40-1.79 (m, 5, CH of ibu and lysine γ and δ CH<sub>2</sub>CH<sub>2</sub>), 2.31 (d, 2, β CH<sub>2</sub>), 2.41-2.52, under dmso (m, 2, β CH<sub>2</sub>), 2.73-3.01 (m, 2, ε CH<sub>2</sub>), 3.51-3.85 (m, 1 ibu CH), 4.01-4.43 (m, 1, α CH), 7.14 (d, 2, ArH), 7.6 (d, 2, ArH), 7.90-8.06 (m, 2, NH).

## EXAMPLE 17

### Summary of the synthesis of [Lysine]<sub>xx</sub> -[Gemfibrozil or Naproxen] or [Glu]<sub>xx</sub> L-DOPA

Synthesis of [Glu]<sub>15</sub> - L-dihydroxyphenylalanine or [Glu]<sub>15</sub>-L-DOPA

L-DOPA (0.050 g, 254 μmol) and GluNCA (0.666 g, 3.85 mmol) were dissolved in 6 ml DMF. After stirring overnight under Argon, the reaction was examined by thin layer chromatography (9:1 H<sub>2</sub>O: HOAc) showed some free drug (R<sub>f</sub> = 0.70) and a more polar spot presumed to be polymer (R<sub>f</sub> = 0.27). The reaction

was quenched by the addition of 12 ml H<sub>2</sub>O. The pH was adjusted to pH 1-2 using 1N HCl. The solvent was removed by rotary evaporation and the viscous residue dried in vacuum. The resultant syrup was transferred to a new vessel in H<sub>2</sub>O and lyophilized. The resulting crystals were off white to light brown. Yield: 0.470 g,

62%. <sup>1</sup>H NMR showed pyroglutamic acid contamination; therefore, the material was suspended in H<sub>2</sub>O and ultrafiltered (Millipore, regenerated cellulose, YM1, NMWL =1000), and the retentate dried under vacuum. Yield: 0.298 grams. <sup>1</sup>H NMR (500MHz, DMSO) indicated a relative ratio of 30:1 Glu:L-DOPA, 6.6 (L-DOPA aromatic), 6.4 (L-DOPA aromatic), 4.1 (Glu, α)

1.85 (Glu, β), 2.25 (Glu, γ, L-DOPA), 2.3 (L-DOPA, benzylic), 12.4-11.5 (Glu, CO<sub>2</sub>H), 8.0 (Glu, amide)

#### Synthesis of [Glu]<sub>10</sub>-L-DOPA

As in the synthesis of [Glu]<sub>15</sub>-L-DOPA except 0.439 grams of GluNCA were used. The final yield of purified material was 0.007 grams.

The <sup>1</sup>H NMR (500MHz, DMSO) indicates 8:1 Glu:L-DOPA.

#### Synthesis of Naproxen-Succinimide

To Naproxen (2.303 g, 10 mmol) in 5 ml of dioxane was added N-hydroxysuccinimide (1.16 g, 10 mmol) dissolved in 15 ml of dioxane and dicyclohexylcarbodiimide (2.27 g, 11mmol) in 25 ml of dioxane. The reaction was stirred overnight and the insoluble dicyclohexylurea removed by filtration. The solvent was removed by rotary evaporation and the residue dissolved in 30-40 ml CH<sub>2</sub>Cl<sub>2</sub>. Approximately 10 ml hexane was added and the mixture was chilled to 4°C for 2 hr. Additional hexane was added dropwise until small planar white crystals

began to form and the solution was refrigerated overnight. The activated ester was harvested, washed with hexane and dried in vacuum (2.30 g, 70.0 %):  $^1\text{H}$  NMR (500MHz, DMSO) 1.70 (d, 3H,  $\text{CH}_3$ ) 2.9 (s, 4H, succinimide), 3.91 (s, 3H,  $\text{OCH}_3$ ), 4.18 (q, 1H, methine) 7.75-7.12 (m, 6H, aromatic).

5

#### Synthesis of polylysine-Naproxen

To  $[\text{Lys}]_{14} \cdot 14 \cdot \text{HBr}$  (0.100 g, 35 mmol) in 1 ml of  $\text{H}_2\text{O}$  (containing 10 mg/ml  $\text{Na}_2\text{CO}_3$ ) was added Naproxen-Succinimide (0.124 g, 379 mmol) in 2 ml of dioxane. After stirring overnight a precipitate formed. More precipitate was formed by the addition of 30–40 ml of  $\text{H}_2\text{O}$  (containing 10 mg/ml  $\text{Na}_2\text{CO}_3$ ), isolated by filtration and washed with 50 ml of  $\text{Et}_2\text{O}$ . The fine white powder was dried (0.095 g, 53%):  $^1\text{H}$  NMR (500MHz, DMSO) 8.1 (m, 1H, lysine; amide), 7.8-7.0 (m, 6H, aromatic), 4.4-4.1 (m, 2H,  $\alpha$ , methine), 3.3 (s, 3H,  $\text{OCH}_3$ ), 2.8 (m, 2H,  $\epsilon$ ), 1.7-1.0 (m, 9H,  $\beta$ ,  $\gamma$ ,  $\delta$ ,  $\text{CH}_3$ ).

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#### Synthesis of Gemfibrozil – Succinimide

To Gemfibrozil (GEM) (5.0 g, 20.0 mmol) in 30 ml dioxane was added N- hydroxysuccinimide (2.3 g, 20.0 mmol) in 20 ml dioxane and dicyclohexylcarbodiimide (4.5 g, 22.0 mmol) in 50 ml dioxane. The reaction was stirred overnight and the insoluble dicyclohexylurea removed by filtration. The solvent was removed by rotary evaporation and the residue dissolved in 15 – 20 ml of  $\text{CH}_2\text{Cl}_2$ . Hexane was added dropwise until crystal formation was seen and the mixture was chilled to  $4^\circ\text{C}$  overnight. Approximately 3 ml of additional n-hexane was added and the mixture chilled to  $-20^\circ\text{C}$  overnight. The activated ester formed small planer crystals and was harvested, washed with hexane and dried in vacuum

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(5.8 g, 80%):  $^1\text{H}$  NMR (500 MHz, DMSO) 1.2, 1.3 (s, 6H,  $\text{CH}_3$ ), 1.8-1.5 (m, 6H, GEM  $\text{CH}_2$ ), 2.3-2.1 (s, 6H, aromatic  $\text{CH}_3$ ) 2.85-2.7 (d, 4H, succinimide  $\text{CH}_2$ ), 7.0-6.6 (m, 3H, aromatic).

## 5 Synthesis of polylysine-Gemfibrozil

To  $[\text{Lys}]_{11} \cdot 11\text{HBr}$  (0.100 g, 43.5  $\mu\text{mol}$ ) in 1 ml of  $\text{H}_2\text{O}$  (containing 10 mg/ml  $\text{Na}_2\text{CO}_3$ ) was added Gemfibrozil-succinimide (0.094 g, 261.1  $\mu\text{mol}$ ) in 2 ml dioxane. After stirring overnight a precipitate formed. More precipitate was formed by the addition of 30 ml of  $\text{H}_2\text{O}$  (containing 10 mg/ml  $\text{Na}_2\text{CO}_3$ ), isolated and washed with 50 ml  $\text{Et}_2\text{O}$ . The fine white powder was dried (0.019 g, 1%):  $^1\text{H}$  NMR (500MHz, DMSO) 1.5-1.0 (m, 12H,  $\beta$ ,  $\gamma$ ,  $\delta$ ,  $\text{CH}_3$ ), 1.85-1.5 (m, 4H,  $\text{CH}_2$ ), 2.3, 2.1 (s, 6H, aromatic  $\text{CH}_3$ ), 3.35 (s, 2H,  $\epsilon$ ), 3.85 (s, 2H,  $\text{OCH}_2$ ), 4.05 (s, 1H,  $\alpha$ ), 5.6 (d, 1H, carbamate), 7.0-6.7 (m, 3H, aromatic), 8.0 (d, 1H, amide).

## 15 EXAMPLE 18

All reagents were used as received.  $^1\text{H}$  NMR was run on a Bruker 300 MHz (300) or JEOL 500 MHz (500) NMR spectrophotometer using tetramethylsilane as an internal standard. Thin layer chromatography was performed using plates precoated with silica gel 60  $\text{F}_{254}$ . Flash chromatography was performed using silica gel 60 (230-400 mesh).

### Preparation of polyArg

#### Method 1

To H-Arg(Z) $_2$ -OH (0.300 g, 0.68 mmol) in 3.0 ml dry DMSO was added diphenylphosphorylazide (219  $\mu\text{l}$ , 1.02 mmol) and triethylamine (236  $\mu\text{l}$ , 1.69 mmol).

The reaction was stirred for 48 h under Ar upon which the solution was poured into 100 ml H<sub>2</sub>O. The resulting heterogeneous solution was centrifuged to isolate the white precipitate which was washed 3 x 100 ml H<sub>2</sub>O, 3 x 100 ml CH<sub>2</sub>OH and 100 Et<sub>2</sub>O and then vacuumed dried to obtain 172 mg of an off white solid: <sup>1</sup>H NMR (500 MHz, DMSO) 7.31 (m, 10H), 5.21 (m, 1H, benzylic), 5.01 (m, 1H, benzylic), 3.83 (m, 1H, α), 3.34 (m, 2H, δ) 1.54 (m, 4H, β, γ).

This material was dissolved in 1.5 ml dry anisole and stirred with 0.3 ml anhydrous methanesulfonic acid for 3 h upon which another 0.3 ml anhydrous methanesulfonic acid was added and the solution stirred for 1 h. The reaction mixture was poured into 6 ml Et<sub>2</sub>O and refrigerated for 15 m. The heterogeneous biphasic mixture was concentrated to 0.5 ml by rotary evaporation. Thrice, an additional 8 ml Et<sub>2</sub>O was added and the biphasic mixture centrifuged and the supernatant removed leaving a yellowish gum. This residue was washed twice with 6 ml acetone, centrifuged and the supernatant discarded leaving behind a white-yellow residue. The residue was dissolved in 0.3 ml H<sub>2</sub>O and shaken with Amberlite IRA-400. The resin was removed by filtration and washed with 3 ml H<sub>2</sub>O. The combined eluent and wash were dried in vacuum yielding a yellow film 0.063 g, (90% yield): <sup>1</sup>H NMR (500 MHz, D<sub>2</sub>O) 4.37 (m, 1H, α), 3.22 (m, 2H, δ) 1.94-1.66 (m, 4H, β, γ); MALDI-MS shows a degree of polymerization varying between six to fourteen residues.

## Method 2

To Boc-Arg(Z)<sub>2</sub>-OH (0.025 g, 0.05 mmol) and H-Arg(Z)<sub>2</sub>-OH (0.280 g, 0.63 mmol) in 3.0 ml dry DMSO was added diphenylphosphorylazide (219 μl, 1.02 mmol) and triethylamine (236 μl, 1.69 mmol). The reaction was stirred for 48 h and then poured into 100 ml H<sub>2</sub>O. The heterogeneous solution was centrifuged and the

precipitate washed 3 x 100 ml H<sub>2</sub>O, 3 x 100 ml CH<sub>3</sub>OH and 100 Et<sub>2</sub>O and then vacuumed dried to obtain 132 mg of solid: <sup>1</sup>H NMR (500 MHz, DMSO) 7.31 (m, 10H), 5.21 (m, 1H, benzylic), 5.01 (m, 1H, benzylic), 3.83 (m, 1H, α), 3.34 (m, 2H, δ) 1.54 (m, 4H, β, γ).

5 The protected polymer was dissolved in 1.5 ml dry anisole and stirred with 1.3 ml anhyd methanesulfonic acid for 4 h. The solution was concentrated to 0.5 ml by rotary evaporation. Et<sub>2</sub>O (8 ml) was added and the biphasic system centrifuged and the supernatant discarded. Thrice, 10 ml acetone was added, the solution centrifuged and the supernatant discarded. The pellet was dried overnight in vacuum and then  
10 dissolved in 0.3 ml H<sub>2</sub>O and shaken with Amberlite IRA-400. The resin was removed by filtration and washed with 3 ml H<sub>2</sub>O. The combined eluent and wash were dried in vacuum yielding a yellow film 0.019, (24% yield); <sup>1</sup>H NMR (500 MHz, D<sub>2</sub>O) 4.37 (m, 1H, α), 3.22 (m, 2H, δ) 1.94-1.66 (m, 4H, β, γ); MALDI-MS shows a degree of polymerization varying between five to eleven residues.

### Preparation of T4 Conjugates

T4 conjugated to aminoacid polymers were either prepared by coupling (protected) T4 to commercially available aminoacid homopolymers or incorporated by polymerization of a T4 moiety with the corresponding N-carboxyanhydride  
20 aminoacid.

#### T4 Conjugation to preformed homopolymers

To N-TeocT4 (0.017 g, 17 μmol) in 1 ml dry DMF was added dicyclohexylcarbodiimide (0.004 g, 18 μmol). After stirring for 30 minutes N-  
25 dimethyl-4-aminopyridine (0.004 g, 36 μmol) and Gly<sub>18</sub> (0.017 g, 17 μmol) were

added and the reaction stirred overnight. The cloudy solution was poured into 20 ml H<sub>2</sub>O and extracted twice with 10 ml CH<sub>2</sub>Cl<sub>2</sub>. The aqueous component was acidified to pH 3 with 1 N HCl and chilled to 4° C. The material was isolated by centrifugation and the pellet thrice washed with 8 ml H<sub>2</sub>O. The pellet was dried in vacuum to yield  
5 dicyclohexylurea and N-TeocT4-Gly<sub>18</sub>: <sup>1</sup>H NMR (500 DMSO) 7.8 (T4 aromatic), 7.1 (T4 aromatic), 4.1 (α).

To the impure protected polymer was added 2 ml trifluoroacetic acid. The reaction was stirred for 2 h and the solvent removed by rotary evaporation. The residue was dissolved in 1 ml DMF and the insoluble material removed by filtration.  
10 The DMF was removed by rotary evaporation and dried in vacuum to yield a white material (.012 g, 40%): <sup>1</sup>H NMR (500 DMSO) 7.75 (T4 aromatic), 7.08 (T4 aromatic), 4.11 (bs, α).

#### Preparation of aminoacid NCA.

15 To the L-aminoacid (1.5 g) in 100 ml dry THF was added triphosgene (0.8 eqv). The reaction vessel was equipped with a reflux condenser and NaOH trap and heated to reflux for 3 h. The solvent was removed by rotary evaporation and the residue washed with hexane to yield the aminoacid NCA as white residue.

LeuNCA: <sup>1</sup>H NMR (500 CDCl<sub>3</sub>) 6.65 (s, 1H, NH), 4.33 (dd, 1H, α), 1.82 (m, 2H, β), 1.68 (m, 1H, γ), 0.98 (dd, 6H, δ).

PheNCA: <sup>1</sup>H NMR (500 CDCl<sub>3</sub>) 7.36-7.18 (m, 5H), 5.84 (s, 1H, NH), 4.53 (dd, 1H), 3.28 (dd, 1H, α), 2.98 (dd, 1H, β).

Trp(Boc)NCA: :  $^1\text{H}$  NMR (500  $\text{CDCl}_3$ ) 8.14 (d, 1H), 7.49 (d, 2H), 7.36 (t, 1H), 7.27 (m, 1H), 5.90 (s, 1H, NH), 4.59 (dd, 1H,  $\alpha$ ), 3.41 (dd, 1H,  $\beta$ ), 3.07 (dd, 1H,  $\beta$ ), 1.67 (s, 9H, t-Bu).

5 IleNCA:  $^1\text{H}$  NMR (300  $\text{CDCl}_3$ ) 6.65 (s, 1H, NH), 4.25 (d, 1H,  $\alpha$ ), 1.94 (m, 1H,  $\beta$ ), 1.43 (dm, 2H,  $\gamma\text{-CH}_2$ ), 1.03 (d, 3H,  $\gamma\text{-CH}_3$ ), 0.94 (t, 3H,  $\delta$ ).

10 Lys(Boc)NCA:  $^1\text{H}$  NMR (500  $\text{CDCl}_3$ ) 6.65 (bs, 1H,  $\text{N}_\text{H}$ ), 4.64 (s, 1H, carbamate NH), 4.31 (t, 1H,  $\alpha$ ), 3.13 (s, 2H,  $\epsilon$ ), 2.04 (m, 2H,  $\beta$ ), 1.84 (m, 2H,  $\delta$ ), 1.48 (m, 11H,  $\gamma$ , t-Bu).

MetNCA:  $^1\text{H}$  NMR (500  $\text{CDCl}_3$ ) 6.89 (s, 1H, NH), 4.50 (dd, 1H,  $\alpha$ ), 2.69 (t, 2H,  $\gamma$ ), 2.10 (m, 1H,  $\beta$ ), 2.08 (m, 4H,  $\beta$ ,  $\delta$ ).

15 Typical preparation of T4 N-capped homopolymers:

T4-Leu<sub>15</sub>

To IleNCA (0.200 g, 1.3  $\mu\text{mol}$ ) in 2.5 ml DMF was added isoleucine (0.012 g, 0.1  $\mu\text{mol}$ ). After stirring overnight under Ar T4-NCA (0.037 g, 0.050  $\mu\text{mol}$ ) was added and the reaction stirred an additional 72 h. The white solution was added to 8 ml  $\text{H}_2\text{O}$ . The heterogeneous solution was chilled to 4° C, centrifuged and the supernatant discarded and the pellet washed with 8 ml  $\text{H}_2\text{O}$ . The dried residue was washed with 50 ml ethanol warmed to 50° C to yield after drying, a white powder (0.124 g, 55%):  $^1\text{H}$  NMR (500 DMSO) 7.75 (s, T4 aromatic), 7.08 (s, T4 aromatic), 4.11 (dd,  $\alpha$ ), 1.77 (m,  $\beta$ ), 1.38 (m,  $\beta$ ,  $\gamma\text{-CH}$ ), 0.91 (m,  $\gamma\text{-CH}$ ,  $\gamma\text{-CH}_3$ ,  $\delta$ ).



#### T4-Phe<sub>15</sub>

White powder (58%): <sup>1</sup>H NMR (360 MHz, DMSO) 7.0-8.1 (NH, aromatics), 4.5 (α), 3.0 (β); MALDI-MS indicates T4-Phe<sub>1-5</sub>.

#### 5 T4-Met<sub>15</sub>

White powder (10%): <sup>1</sup>H NMR (500MHz, DMSO) 8.0-8.5 (amide NH) , 4.4 (α) 2.5 (γ), 2.05 (ε), 2.0-1.7 (β).

#### T4-Val<sub>15</sub>

10 White powder (14%): <sup>1</sup>H NMR (500MHz, DMSO) 7.75 (T4 aromatic), 7.08 (T4 aromatic), 4.35 (α), 3.45 (β), 1.05 (γ).

For those conjugates that used a protected NCA an additional, separate deprotection step was necessary:

15

To T4-[Lys(Boc)]<sub>15</sub> (0.256 g, 61 μmol) in 10 ml of CH<sub>2</sub>Cl<sub>2</sub> was stirred with trifluoroacetic acid (10 ml) for 2 h. The solvent was removed by rotary evaporation and the residue dissolved in 3 ml H<sub>2</sub>O and ultrafiltered (Amicon regenerated cellulose, YM1, NMWL 1000, wash with 30 ml pH 5 H<sub>2</sub>O). The retentate was dried  
20 in vacuum to give a light brown residue: <sup>1</sup>H NMR (500 D<sub>2</sub>O) 7.82 (s, T4 aromatic), 7.41 (s, T4 aromatic), 4.29 (bs, α), 3.00 (bs, ε), 2.13-1.70 (m, β, δ, γ); MALDI-MS gives a range T4-Lys<sub>4-11</sub>.

T4-Trp<sub>15</sub>: <sup>1</sup>H NMR (500 DMSO) 8.25-6.80 (m, aromatic), 4.50 (bs, α), 3.40  
25 (bs, β), 3.00 (bs, β).

Typical preparation of T4 C-capped homopolymers:

To T4 (0.078 g, 100  $\mu$ mol) in 10 ml dry DMF was added Trp(Boc)NCA (0.500 g, 1.514 mmol). After stirring for 64 h under Ar the reaction was quenched by adding 30 ml H<sub>2</sub>O. The cloudy white solution was chilled to 4° C, centrifuged and the pellet washed three times with 25 ml H<sub>2</sub>O. The residue was dried in vacuum to provide Trp(Boc)<sub>15</sub>-T4 as a brown solid. This material was further purified by ultrafiltration (Amicon regenerated cellulose, YM1, NMWL 1000, wash with 30 ml pH 5 H<sub>2</sub>O) to provide [Trp(Boc)]<sub>15</sub>-T4 as a brown-gold solid (0.400 g, 79%): <sup>1</sup>H NMR (500 DMSO) 8.25-6.80 (m, aromatic), 4.50 (bs,  $\alpha$ ), 3.40 (bs,  $\beta$ ), 3.00 (bs,  $\beta$ ), 1.50 (bs, t-Bu).

To [Trp(Boc)]<sub>15</sub>-T4 (0.509 g) in 8 ml of 1:1 CH<sub>2</sub>Cl<sub>2</sub>: trifluoroacetic acid was stirred for 1.5 h. The solvent was removed by rotary evaporation and the residue dried in vacuum to yield a brown solid (0.347 g, 97%): <sup>1</sup>H NMR (500 DMSO) 8.25-6.80 (m, aromatic), 4.50 (bs,  $\beta$ ), 3.40 (bs,  $\alpha$ ), 3.00 (bs,  $\beta$ ).

[Lys(Boc)]<sub>15</sub>-T4: <sup>1</sup>H NMR (500 D<sub>2</sub>O) 7.82 (s, T4 aromatic), 7.41 (s, T4 aromatic), 4.29 (bs,  $\alpha$ ), 3.00 (bs,  $\epsilon$ ), 2.13-1.70 (m,  $\beta$ ,  $\delta$ ,  $\gamma$ ).

Lys<sub>15</sub>-T4: <sup>1</sup>H NMR (500 D<sub>2</sub>O) 7.82 (s, T4 aromatic), 7.41 (s, T4 aromatic), 4.29 (bs,  $\alpha$ ), 3.00 (bs,  $\epsilon$ ), 2.13-1.70 (m,  $\beta$ ,  $\delta$ ,  $\gamma$ ).

Typical preparation of random T4/homopolymers:

To T4NCA (0.065 g, 0.1 mmol) and Trp(Boc)NCA (0.400 g, 1.2 mmol) were combined in 4 ml dry DMF. Triethylamine (11  $\mu$ l, 0.1 mmol) was added and the

reaction stirred for 44 h under Ar. After quenching by the addition of 10 ml H<sub>2</sub>O the heterogeneous mix was chilled to 4° C and centrifuged. The pellet was isolated and washed three times with 10 ml H<sub>2</sub>O and dried in vacuum.

To the random T4/[Trp(Boc)]<sub>15</sub> polymer was added 10 ml 1:1 CH<sub>2</sub>Cl<sub>2</sub>:

5 trifluoroacetic acid and the reaction stirred for 1 h. The solvent was removed by rotary evaporation to provide the deprotected polymer as a brown solid (0.262 g, 91%) which was further purified by ultrafiltration (Amicon regenerated cellulose, YM1, NMWL 1000, wash with 30 ml pH 5 H<sub>2</sub>O): <sup>1</sup>H NMR (500 DMSO), 8.25-6.80 (m, aromatic), 4.50 (bs, α), 3.40 (bs, β), 3.00 (bs, β).

10 Random T4/Lys<sub>15</sub>: <sup>1</sup>H NMR (500 D<sub>2</sub>O); 7.82 (s, T4 aromatic), 7.41 (s, T4 aromatic), 4.29 (bs, α), 3.00 (bs, ε), 2.13-1.70 (m, β, δ, γ).

### Preparation of PolyLysine Depakote

15 To valproic acid (1.0 g, 6.9 mmol) in 14 ml 6:1 CH<sub>2</sub>Cl<sub>2</sub>:DMF was added N-hydroxysuccinimide (0.8 g, 6.9 mmol), dicyclohexylcarbodiimide (1.6 g, 7.6 mmol) and triethylamine (0.9 g, 8.9 mmol). The reaction was stirred for 60 h whereupon the solution was filtered to remove the white precipitate and the solvent removed by rotary evaporation. The residue was purified by flash chromatography (10:1-2:1  
20 hexane:EtOAc) to provide the succinimidyl ester as a clear oil (1.0 g, 59%): R<sub>f</sub> (3:1 hexane:EtOAc) 0.43; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) 2.76 (s, 4H, succinimide), 2.61 (m, 1H, methine), 1.65-1.19 (m, 8H, methylene), 0.88 (t, 6H, methyl).

To Lys<sub>14</sub>HBr (0.106 g, 37 μmol) in 0.8 ml H<sub>2</sub>O pH 8 was added the valproic succinimidyl ester (0.104 g, 431 μmol) dissolved in 0.4 ml THF. The reaction was  
25 stirred overnight whereupon 8 ml H<sub>2</sub>O was added. The mixture was acidified to pH 3

with 6 M HCl and extracted twice with 2 ml CH<sub>2</sub>Cl<sub>2</sub>. The aqueous layer was dried and the residue dissolved in 1 ml H<sub>2</sub>O. The solution was purified by SEC (G-15, 10 ml dry volume) and eluted with water. Those fractions containing conjugate were combined and dried to yield a white solid (0.176 mg) which by NMR indicated 28

- 5 Lysine for every one drug molecule; <sup>1</sup>H NMR (D<sub>2</sub>O) 4.29 (m, 1H, α), 3.00 (m, 2H, ε), 1.87-1.68 (m, 4H, β, δ), 1.43 (m, γ, methylene), 0.85 (t, methyl).

### Preparation of PolyGlu Mevastatin

AcNGlu<sub>15</sub>(3-mevastatin)<sub>2</sub>

- 10 To polyGlu<sub>15</sub> (0.116 g, 69 μmol) in 3 ml dry DMF was added 1 ml pyridine and acetic anhydride (20 μl, 207 μmol). After stirring for 21 h the mixture was acidified with 6 N HCl until pH 1 and then cooled to 4° C. The white precipitate was collected by centrifugation and washed three times with H<sub>2</sub>O and then dried under vacuum to yield 11 mg of N-acetylated polyGlu<sub>15</sub>.

- 15 To N-acetylated polyGlu<sub>15</sub> (0.011 g, 7 α mol) in 4.8 ml dry DMF was added dicyclohexylcarbodiimide (0.022 g, 108 μmol). After stirring twenty minutes the heterogeneous solution was filtered to remove insoluble dicyclohexylurea and combined with mevastatin (0.042 g, 108 μmol) and N-dimethyl-4-aminopyridine (0.013 g, 108 μmol). The mixture stirred for 23 h whereupon the reaction was
- 20 quenched by the addition of 20 ml H<sub>2</sub>O. The solution was extracted twice with 10 ml CHCl<sub>3</sub>. The aqueous component was adjusted to pH 3 with 1 N HCl and cooled to 4° C. The resultant white precipitate was isolated by centrifugation and washed three times with 8 ml H<sub>2</sub>O. The solid was dissolved in 1 ml H<sub>2</sub>O and washed with 1 ml CH<sub>2</sub>Cl<sub>2</sub> and twice with 2 ml EtOAc. The aqueous layer was acidified to pH 3 with 1
- 25 N HCl, cooled to 4° C, the precipitate isolated by centrifugation and washed twice

with 2 ml H<sub>2</sub>O. The dried conjugate (2 mg) was shown by <sup>1</sup>H NMR to contain fifteen Glu for every two mevastatin molecules: <sup>1</sup>H NMR (500 MHz, DMSO) 5.92 (5' mevastatin), 5.72 (3' mevastatin), 5.19 (4' mevastatin), 5.17 (8' mevastatin), 5.12 (3 mevastatin), 4.41 (5 mevastatin), 4.03 (α, Glu), 2.25 (γ, Glu), 1.88 (β, Glu), 0.82 (4'',2' allylic methyl mevastatin), 1.17 (2'' mevastatin).

#### Glu<sub>15</sub>(3-mevastatin) (160)

To Glu<sub>15</sub> (0.151 g, 77 μmol) in 3 ml dry DMF was added dicyclohexylcarbodiimide (0.239 g, 1.159 mmol) and the reaction stirred for 4 h under Ar. The white precipitate was removed and N-dimethyl-4-aminopyridine (0.141 g, 1.159 mmol) and mevastatin (0.222 g, 0.569 mmol) were added dissolved in 10 ml CHCl<sub>3</sub>. The reaction stirred for 21 h under Ar whereupon the precipitate was removed. The solution was concentrated by rotary evaporation and added to 40 ml saturated NaCl (aq) adjusted so pH 8. The homogeneous solution was extracted three times with 20 ml CHCl<sub>3</sub> and then ultrafiltered (Amicon regenerated cellulose, YM1, NMWL 1,000). The retentate was dried in vacuum to yield 8 mg of a white residue which showed a ratio of 15 Glutamic acids to one mevastatin by <sup>1</sup>H NMR (500 D<sub>2</sub>O); 5.92 (5' mevastatin), 5.72 (3' mevastatin), 5.19 (4' mevastatin), 5.17 (8' mevastatin), 5.12 (3 mevastatin), 4.41 (5 mevastatin), 4.03 (α, Glu), 2.25 (γ, Glu), 1.88 (β, Glu), 0.82 (4'',2' allylic methyl mevastatin), 1.17 (2'' mevastatin).

#### BocGlu(3-mevastatin)O-t-Bu

To BocGlu(OSu)O-t-Bu (0.181 g, 453 μmol) and mevastatin (0.177 g, 453 μmol) in 40 ml CHCl<sub>3</sub> was added N-dimethyl-4-aminopyridine (0.055 g, 453 μmol).

The reaction was heated to reflux for 7 h under Ar and then allowed to stir at 20° C

for 8 h. The solvent was removed by rotary evaporation and the residue purified by flash chromatography (8:1-1:1 hexane:EtOAc) to provide the conjugate as a clear film (0.038 g, 11%):  $R_f$  (3:1 hexane:EtOAc) 0.22;  $^1\text{H}$  NMR ( $\text{CDCl}_3$  500 MHz) 5.97 (d, 1H, 5'), 5.73 (dd, 1H, 3'), 5.55 (s, 1H, 4'), 5.32 (s, 1H, 8'), 5.24 (dd, 1H, 3), 5.09 (d, 1H, NH), 4.48 (m, 1H, 5), 4.20 (m, 1H,  $\alpha$ ), 2.78 (m, 2H, 2), 2.37 (m, 4H, 2', 2'',  $\gamma$ ), 1.45 (s, 18H, t-Bu), 1.12 (d, 3H, 2''-CH<sub>3</sub>), 0.88 (m, 6H, 4'', 2'-CH<sub>3</sub>).

### Preparation of PolyGlu Prednisone

#### BocGlu(21-Prednisone)O-t-Bu

To BocGlu-O-t-Bu (0.400 g, 1.32 mmol) in 20 ml  $\text{CHCl}_3$  was added dicyclohexylcarbodiimide (0.544 g, 2.64 mmol). The reaction was stirred for 1 h and filtered to remove insoluble dicyclohexylurea. N-dimethyl-4-aminopyridine (0.320 g, 2.64 mmol) and prednisone (0.472 g, 1.32 mmol) was added. The reaction was stirred for 60 h and filtered. The solvent was removed by rotary evaporation and the residue purified by flash chromatography (10:1-0:1 hexane:EtOAc) to provide the target as a clear film (0.256 g, 31%):  $R_f$  (6:1  $\text{CHCl}_3$ :MeOH) 0.54;  $^1\text{H}$  NMR ( $\text{CDCl}_3$  500 MHz) 7.68 (d, 1H, 1), 6.16 (d, 1H, 2), 6.04 (s, 1H, 4), 5.15 (d, 1H, NH), 5.03 (d, 1H, 21), 4.71 (d, 1H, 21), 4.08 (t, 1H,  $\alpha$ ), 1.40 (s, 18H, t-Bu).

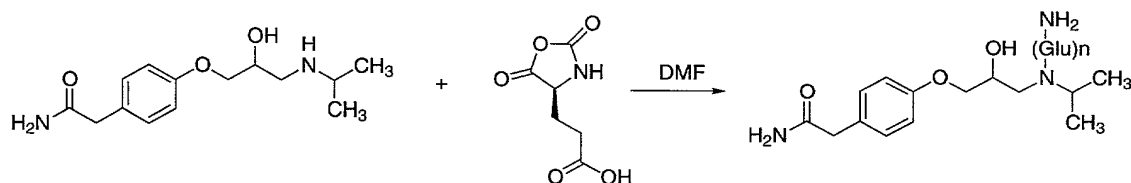
#### Glu(21-Prednisone)

To BocGlu(21-Prednisone)O-t-Bu (0.060 g, 93  $\mu\text{mol}$ ) in 15 ml  $\text{CH}_2\text{Cl}_2$  was stirred for 1 h with trifluoroacetic acid (1.5 ml). The solvent was removed by rotary evaporation and the residue purified by flash chromatography (8:1  $\text{CHCl}_3$ :MeOH) to yield a clear film:  $R_f$  (6:1  $\text{CHCl}_3$ :MeOH) 0.13  $^1\text{H}$  NMR ( $\text{CDCl}_3$  500 MHz) 7.72 (d, 1H, 1), 6.25 (d, 1H, 2), 6.14 (s, 1H, 4), 5.14 (d, 1H, 21), 4.75 (d, 1H, 21), 4.10 (t, 1H,  $\alpha$ ).

## EXAMPLE 19

### Amine-Initiated Polymerization of L-Glutamic Acid NCA

The following procedure was successfully used to synthesize the polyglutamic acid conjugate of atenolol.



MW (g/mole)	266.3	173	1538 (n=10)
Mass (mg)	77	500	446 = 100%
mmoles	0.29	2.89	0.29
equivalents	1	10	1

DMF is dimethylformamide, anhydrous, and was purchased from Aldrich.

Glassware was oven-dried prior to use.

1. Glu-NCA (500 mg, 2.89 mmoles) was dissolved in 4 mL of DMF and stirred under Ar in a 15 mL roundbottom flask equipped with a gas inlet tube.
2. Atenolol, dissolved in 1 mL of DMF, was added to this solution of Glu-NCA and allowed to stir at room temperature for 72 h. In general, the reactions can be run until there is no free amine initiator by tlc. For this reaction, tlc was run using silica plates and eluting with 20% methanol in ethyl acetate.
3. The reaction was quenched by pouring into 20 mL of 10% sodium bicarbonate in water (pH = 8).
4. The water was washed with 3 X 20 mL of methylene chloride and 3 X 20 mL of ethyl acetate.

5. Combined aqueous layers were brought to a pH of 6 with 6N HCl and reduced to a volume of about 20 mL by rotary evaporation. This solution was then cooled in the refrigerator for > 3 hours.

6. To precipitate the polymeric product, the aqueous solution was then acidified to a pH of about 2 using 6N HCl and placed back in the refrigerator for 1-2 hours.

7. The suspension was poured by portions into a 10 mL test tube and centrifuged for 15 minutes until the precipitate formed a solid pack at the bottom of the tube from which the water could be decanted. (At this point in the general procedure, it is preferable that the solid be filtered through a filter funnel and washed with acidic water. The centrifuge was used for atenolol because the solid was too thin to filter.)

8. The solid was then resuspended in acidic water (pH about 2) and vortexed before being centrifuged again and the water decanted. This procedure was repeated once more for a total of three washes.

9. The solid was then dried by high vacuum overnight yielding 262 mg (59%) of polymer. NMR analysis indicated that the Glu/Atenolol ratio was about 30/1.

## EXAMPLE 20

Monolayers of Caco-2 human intestinal epithelial cells are increasingly being used to predict the absorption of orally delivered drugs. We used the Caco-2 transwell system and other *in vitro* assays to evaluate the performance of Polythroid. Our findings indicate that Polythroid may enhance oral delivery of thyroid hormones for the treatment of hypothyroid disorders.



## ***IN VITRO* PERFORMANCE**

### **Caco-2 human intestinal epithelial cell assay**

5 Caco-2 cells are grown on the surface of collagen coated wells in a 24 well format to form confluent monolayers that represent small segments of the intestine. The wells are removable and contain a top chamber representing the apical side (facing the lumen of the intestine) and a bottom chamber representing the basolateral side (site of serosal drug absorption). The integrity of the epithelial barrier is monitored by testing  
10 the electrical resistance across the monolayer. Absorption of drugs can be studied by adding sample to the apical side and assaying the concentration of the drug in the basolateral chamber following incubation.

### **Intestinal epithelial cell proteases digest Polythroid**

15 Polythroid is a synthetic polymer of glutamic acid with T4 and T3 covalently attached by a peptide bond linkage. The polymer is the delivery vehicle for the thyroid hormones and is not designed to cross the intestinal barrier itself. Rather, it is designed to release T4 and T3 in a time dependent manner. Release of the thyroid hormones is dependent on the enzymatic cleavage of the glutamic acid polymer. In  
20 theory, this will result from Polythroid encountering proteolytic enzymes as it descends the intestinal tract. Proteins are digested into small polypeptides by gastric pepsin and pancreatic enzymes secreted into the small intestine. Intestinal epithelial cells then function to further breakdown the small polypeptides. They accomplish this with proteolytic enzymes referred to as brush border proteases that are attached to the  
25 cell surface.

Monitoring the effect of brush border peptidases on Polythroid required development of an assay to specifically distinguish Polythroid from polyglutamic acid and the thyroid hormones. Therefore, we developed an enzyme-linked  
5 immunosorbent assay (ELISA) that specifically recognizes Polythroid. The assay employs antibodies against the glutamic acid polymer to capture Polythroid and antibodies to T4 or T3 to detect the presence of Polythroid. The assay has no cross-reactivity with polyglutamic acid or the thyroid hormones themselves. Consequently, proteolytic degradation of Polythroid results in T4 and T3 release from the polymer  
10 and a corresponding decrease in ELISA reactivity. The Polythroid specific ELISA can, therefore, be used to monitor the breakdown of Polythroid.

The Polythroid specific assay was used to analyze *in situ* digestion of Polythroid in Caco-2 cell cultures. Different concentrations of Polythroid were added  
15 to the apical side of Caco-2 cells and incubated for 4 hours in PBS at 37°C (n=4). The apical side Polythroid concentration was measured by Polythroid specific ELISA before and after the 4 hour incubation (Fig. 6). At the relatively high concentration of 100 micrograms, 26% of Polythroid was degraded, whereas at a 10-fold lower concentration 84% of the Polythroid was degraded. When a concentration of 0.5  
20 micrograms was added (closer to the concentrations that would be encountered by the intestine in a normal human dose) the amount of Polythroid remaining after 4 hours of incubation was below the limit of detection for the ELISA (10 ng) indicating essentially complete digestion. The loss of Polymer in the apical chamber was not due to absorption of Polythroid across the monolayer since the basolateral chamber  
25 contained no detectable Polythroid in any of the experiments (see below). We cannot

rule out cellular uptake of Polythroid, however, enzymatic digestion is likely to account for most, if not all, of the decrease in Polythroid concentration on the apical side. At the higher concentrations, it would be difficult for cellular uptake to account for such a large difference in the remaining Polythroid.

5

Polythroid enhances absorption of T4 across Caco-2 monolayers

**Absorption of T4 was monitored in the Caco-2 transwell system (n=4).**

**Polythroid (10 micrograms) was added to the apical side of the transwells. T4 was added to the apical side at a concentration equal to the T4 content of**

10

**Polythroid. A commercial ELISA for T4 was used to determine the level of T4 in the basolateral chamber following incubation for 4 hours at 37°C (Fig. 7). A significantly higher amount of T4 was absorbed from Polythroid as compared to CaCo-2 cells incubated with the amount of T4 equivalent to that contained in the polymer .**

15

**Polythroid does not cross Caco-2 monolayers**

In order to determine if Polythroid itself crosses the Caco-2 monolayer we used the Polythroid specific ELISA to measure the amount of polymer in the basolateral chamber after incubation with Polythroid at a high concentration (100 micrograms).

20

After 4 hours incubation, samples (n=4) from the basolateral side showed no reactivity in the ELISA (Fig. 8). The limit of detection for Polythroid is 10 ng, therefore, less than 1/10,000 of the Polythroid was absorbed. In conclusion, within the limits of ELISA detection, Polythroid does not cross the Caco-2 monolayer.

25

**Digestion of Polythroid in gastric and intestinal simulators**

Pepsin secreted by the gastric mucosa is the only protease active in the acid conditions of the stomach. The pancreas secretes a number of proteolytic enzymes into the intestine which degrade proteins and polypeptides. In theory, these endogenous proteases will participate in release of T4 and T3 from Polythroid as the polymer descends the intestinal tract.

We tested Polythroid in the USP gastric simulator and the USP intestinal simulator and compared the levels of digestion for Polythroid synthesized by different methods. The samples of Polythroid varied in the position of thyroid hormone attachment.

Samples were dissolved in gastric simulator buffer containing pepsin or in intestinal simulator buffer containing pancreatic enzyme extract (pancreatin) and incubated for 24 hours at 37°C. Following digestion, samples were analyzed by HPLC for the content of released monomeric T4 and T3. Figures 9 and 10 show the levels of T4 and T3 following digestion in the gastric and intestinal simulators. Release varied depending on the position of thyroid hormone attachment. Polythroid with T4 and T3 attached at the C-terminus (C-capped) showed the highest level of digestion. On the other hand, Polythroid with N-terminal attachment (N-capped) showed no digestion in the gastric simulator and a relatively low amount of digestion in the intestinal simulator. Polythroid with random attachment showed only marginal digestion in the gastric simulator and moderate digestion in the intestinal simulator. In conclusion, the rate of thyroid hormone release from Polythroid varies depending on the method of synthesis. This provides a potential means of controlling (fine tuning) time release of oral delivery.

## Conclusions and Summary

The following conclusions can be drawn from *in vitro* performance assays:

- T4 and T3 are released from Polythroid by pancreatic and intestinal cell proteases
- T4 and T3 released from Polythroid are absorbed across intestinal monolayers
- 5 • Polythroid enhances absorption of T4 across intestinal epithelium *in vitro*
- Polythroid itself does not cross the intestinal epithelial barrier *in vitro*
- The kinetics of time release may be controlled by the method of Polythroid synthesis

10 Covalent attachment of T4 and T3 to a polypeptide affords a number of potential advantages to oral delivery for thyroid hormone replacement therapy. Proteolytic enzymes produced by the pancreas and intestinal epithelial cells release T4 and T3 from Polythroid. Therefore, T4 and T3 should be released in a time dependent manner as they descend the intestinal tract. Once released the hormones are  
15 absorbed across the intestinal epithelium in the Caco-2 cell model. In addition, data from the *in vitro* intestinal epithelial model suggests that attachment of T4 to polymers of glutamic acid may enhance absorption of the thyroid hormones, perhaps by providing a second mechanism of uptake and/or enhancing solubility of the hormones. Polythroid itself does not cross the intestinal epithelial barrier in the *in*  
20 *vitro* Caco-2 model. Thus, any concerns about systemic effects of the polymer are minimized since it should not be absorbed into the bloodstream.

Although illustrated and described above with reference to specific embodiments, the invention is nevertheless not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope

and range of equivalents of the claims and without departing from the spirit of the invention.

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	